Insight on additional work on 4D QUBO tracking at Muon Colliders

Research ideas for the remaining PhD year

David Spataro
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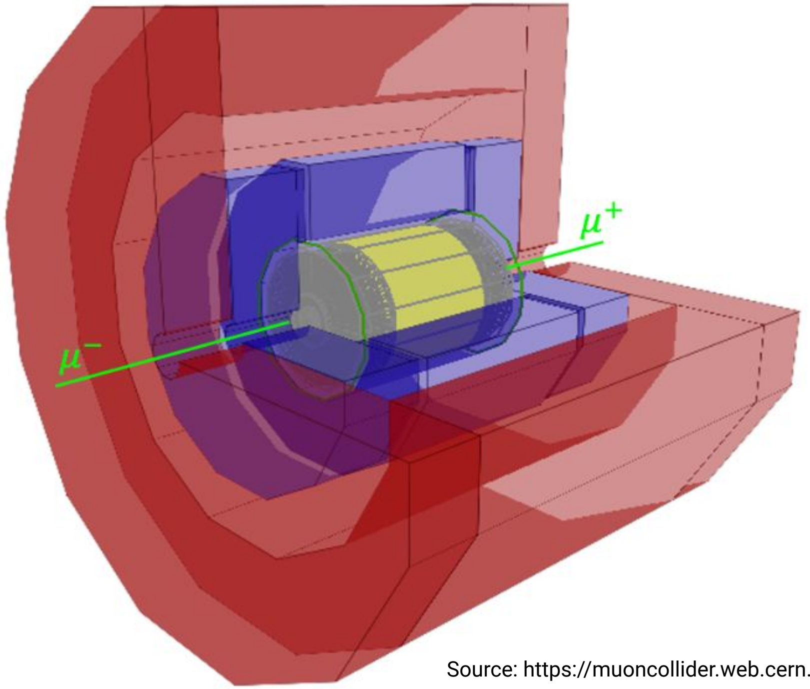
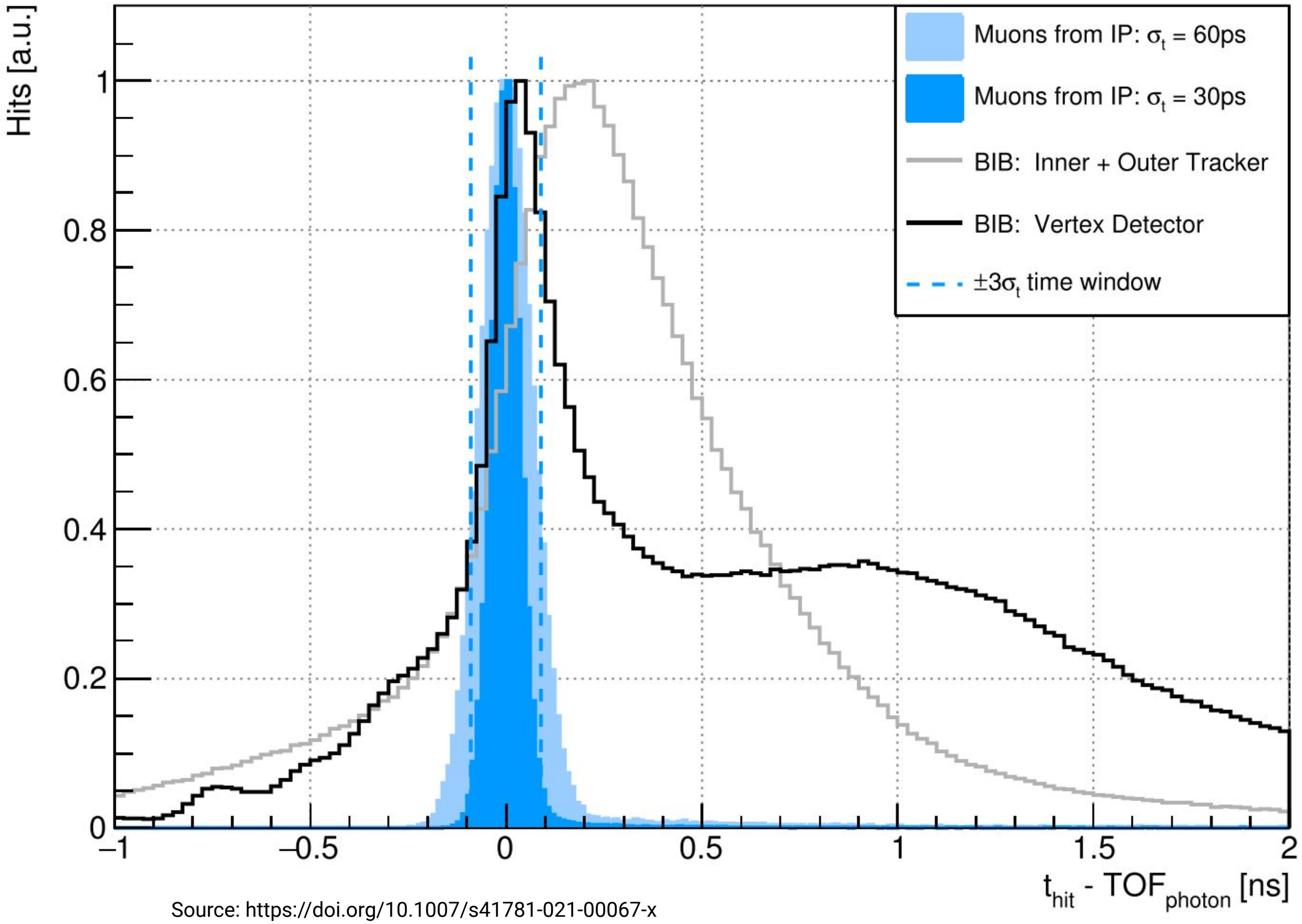
Additional work: 4D QUBO tracking at Muon Colliders

Myon decays result in secondary and tertiary particles (***B***eam-***I***nduced-***B***ackground)

Challenge: Identify signal tracks within a large background



Source: https://muoncollider.web.cern.ch



Source: https://doi.org/10.1007/s41781-021-00067-x

Measuring Track Reconstruction

Quadratic ***U***nconstrained ***B***inary ***O***ptimisation as Hamiltonian formulation of the track reconstruction:

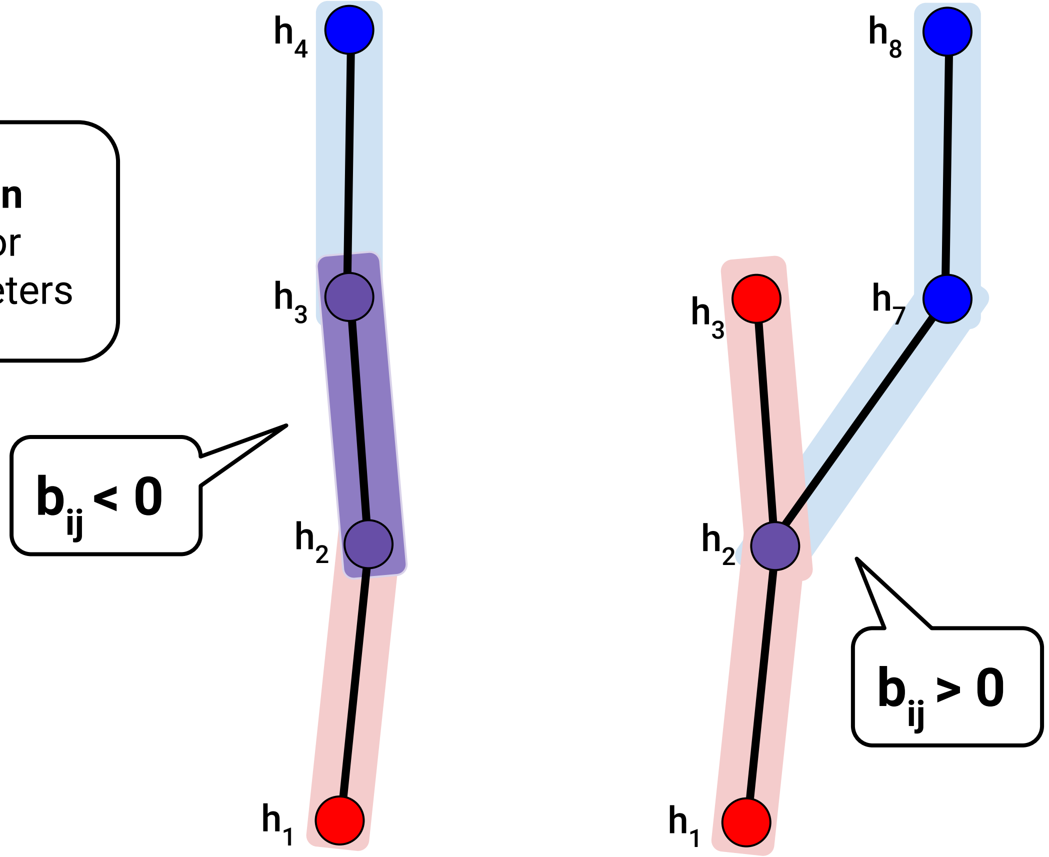
$$\hat{H} = \sum_{i}^{N} \sum_{j<i} b_{ij} T_i T_j + \sum_{i=1}^{N} a_i T_i$$

- $\mathbf{T_i} \in \{0, 1\}$ as binary representation of a triplet
  $\mathbf{t_{bin}}$: $[T_1, T_2, T_3, \dots, T_N] \rightarrow [0, 1, 1, \dots, 0]$
- $\mathbf{b_{ij}}$ as interactions of triplets
- $\mathbf{a_i}$ as quality of a triplet

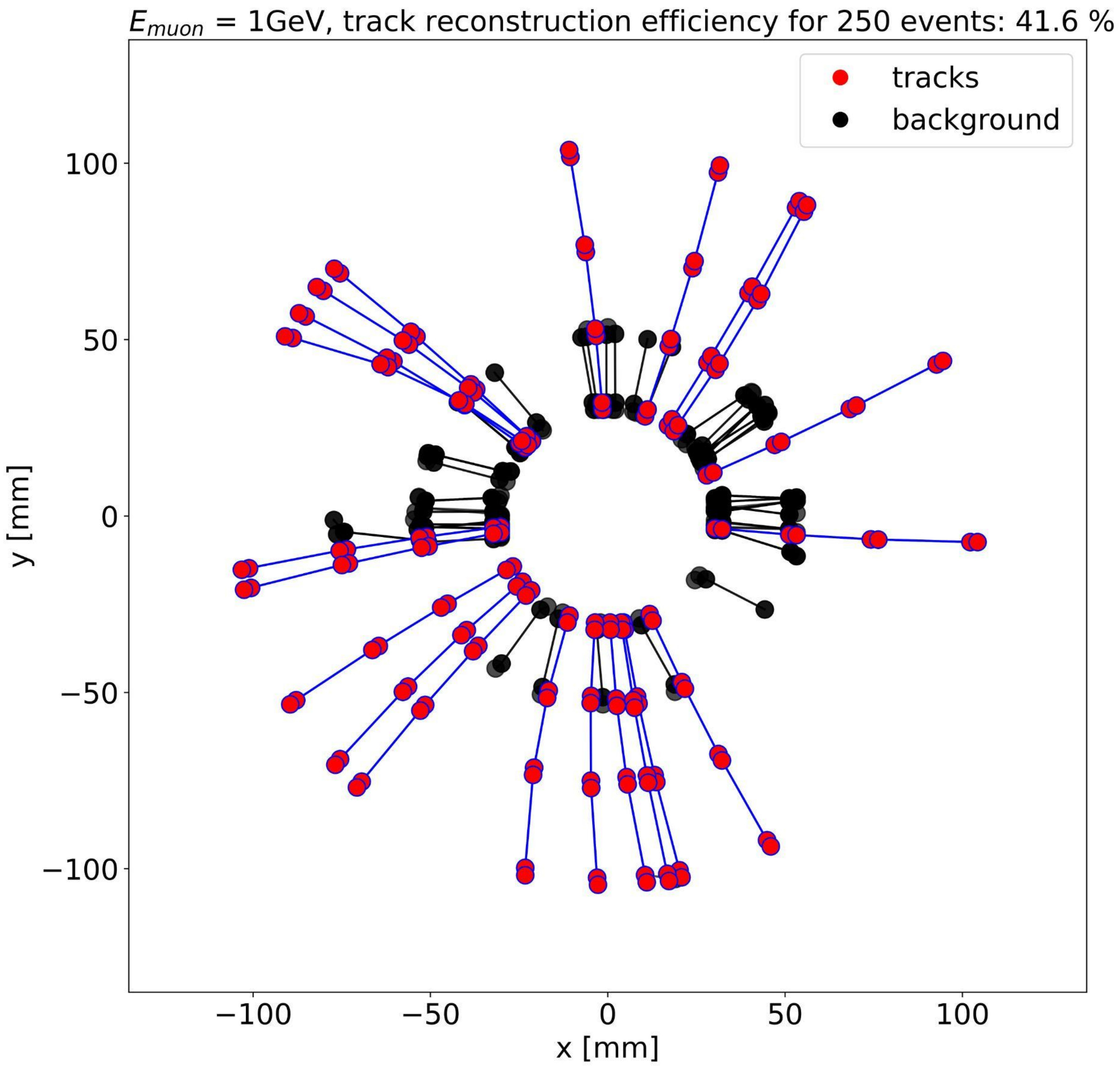
time + position information for QUBO parameters

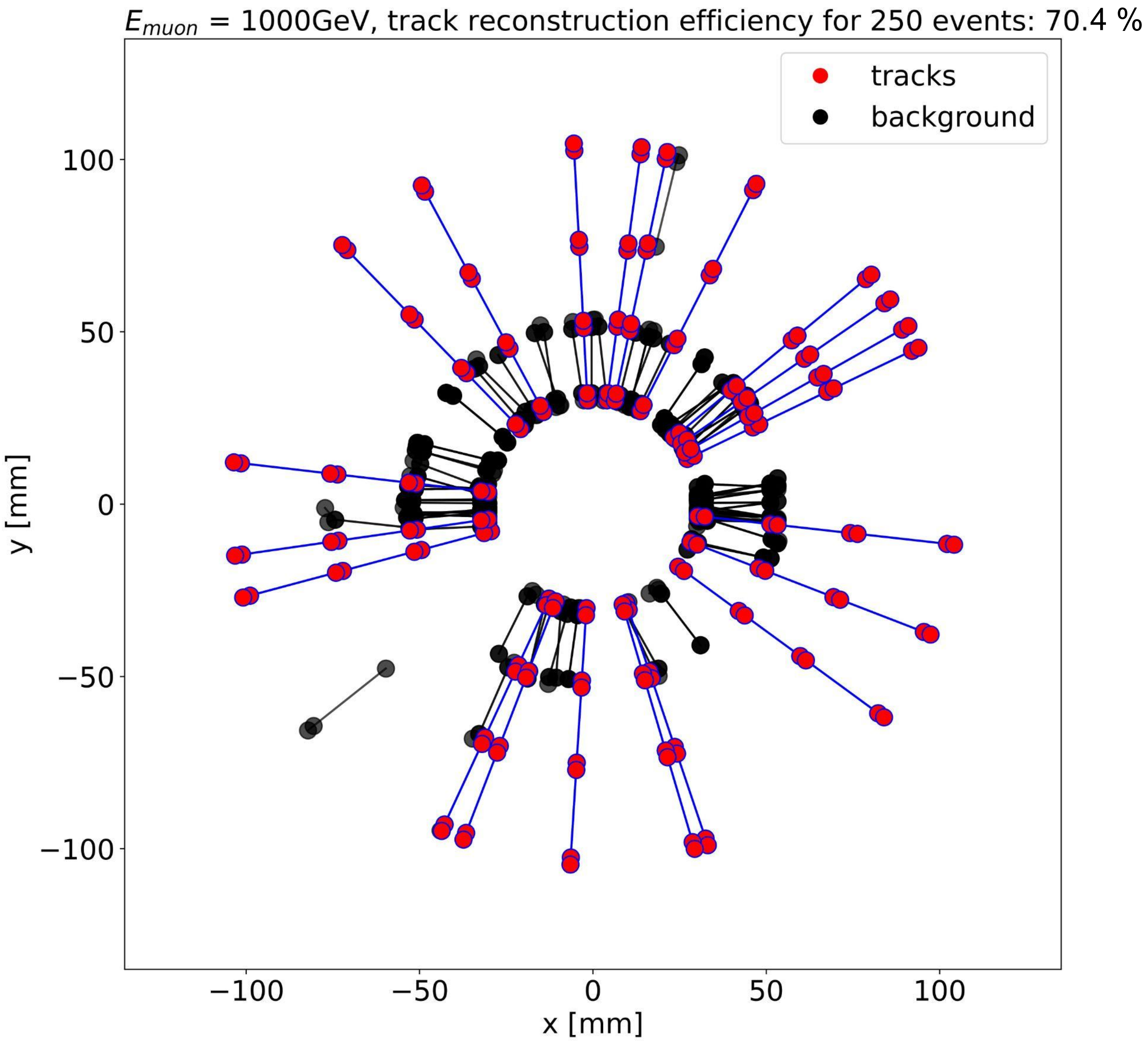
Ground state of the Hamiltonian is the optimal solution of the track reconstruction task

→ resulting binary vector $\mathbf{t_{bin}}$ tells which triplets to keep



4D QUBO results - 25 example tracks





Research ideas for the remaining PhD year - Part I

Impact list $\rightarrow$ connection list:

- Reason: Impact list not suited for our backend size vs. problem size ratio
- Connection list as natural approach to address problem topology
- First very basic implementation in place and (pre-)study already performed.

  Findings so far:
  - Faster convergence
  - Better result (higher efficiency + lower fake rate)
  - Scales with QUBO size

Research ideas for the remaining PhD year - Part II

TwoLocal ansatz → HamiltonianDriven ansatz:

- Reason: a quantum circuit with a fixed entanglement scheme not representing the physical conditions is harder to optimise
- Implementation in place and study already performed for DPG 2022.
- Combination of connection list approach + Hamiltonian driven ansatz interesting, especially for subqubo sizes > 10

Research ideas for the remaining PhD year - Part III

NFT Optimiser → ?

- Problem: Only updating one parameter at a time is not suitable for complex quantum circuits → whac - a - mole optimisation
- Idea: Build a custom optimiser, because
  - Tracking problem is not quantum mechanical in the first place → We want a 100% answer (ideal simulation) not a probability, but due to superposition of local solutions we might still end ab with “just” a probability
  - Allow a finite set of parameter values e.g. theta = [0, ¼, ½, ¾, 1]
  - Optimiser may need to “know” Hamiltonian structure to some degree and maybe update not only one parameters at a time to not mess up the result