Thoughts and plans towards the paper

Federico Meloni (DESY), summarising a
few discussions with Annabel, David and Yee

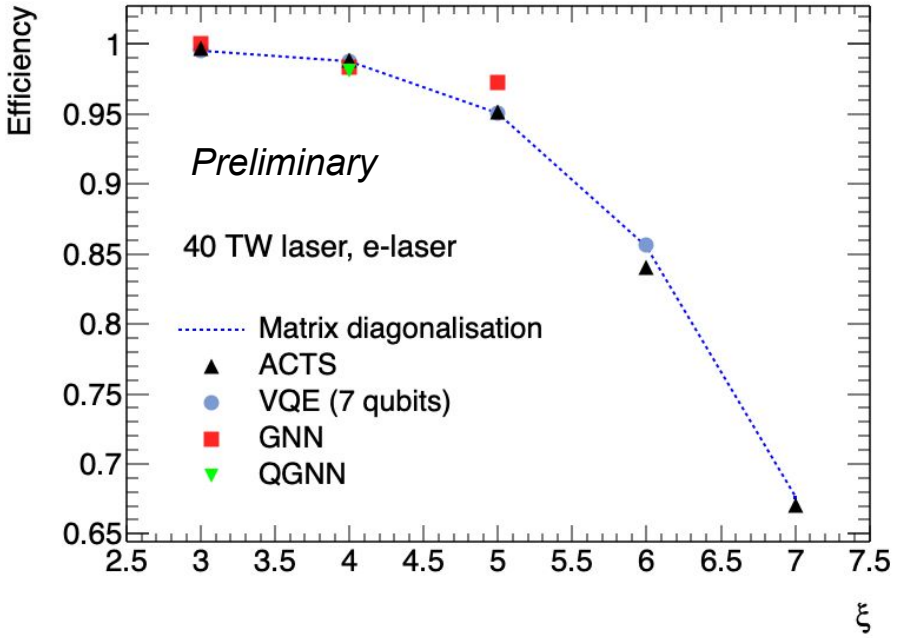
LUXE QC meeting
08/02/2023

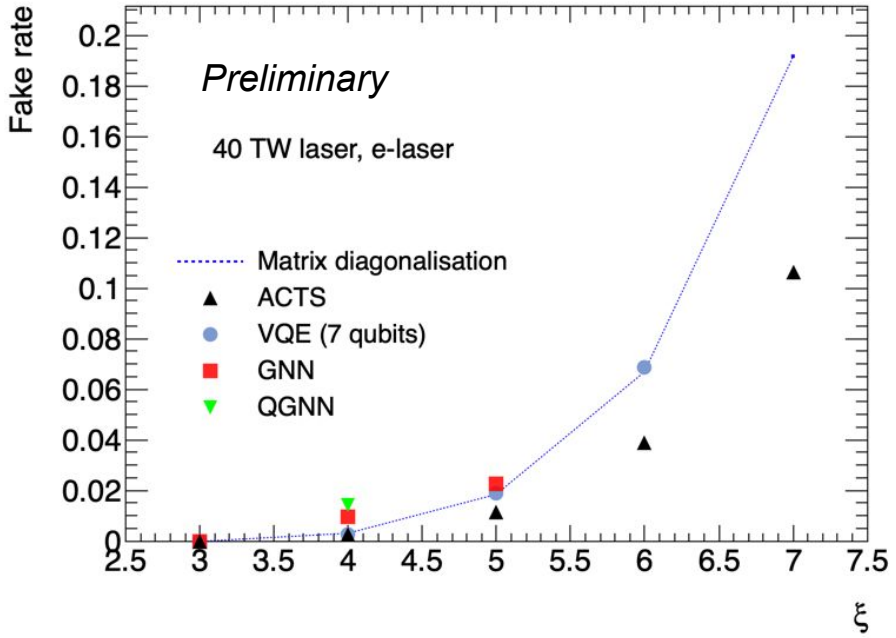
Where we are

Average efficiency and fake rates

$$\text{Efficiency} = \frac{N_{\text{tracks}}^{\text{matched}}}{N_{\text{tracks}}^{\text{generated}}}$$

$$\text{Fake rate} = \frac{N_{\text{tracks}}^{\text{fake}}}{N_{\text{tracks}}^{\text{reconstructed}}}$$





Excellent performance, in line with classical approaches

Several (new) open questions

GOAL: Address satisfactorily the most urgent questions, without regressing to full R&D mode

Impact list

sub-QUBO size = 12

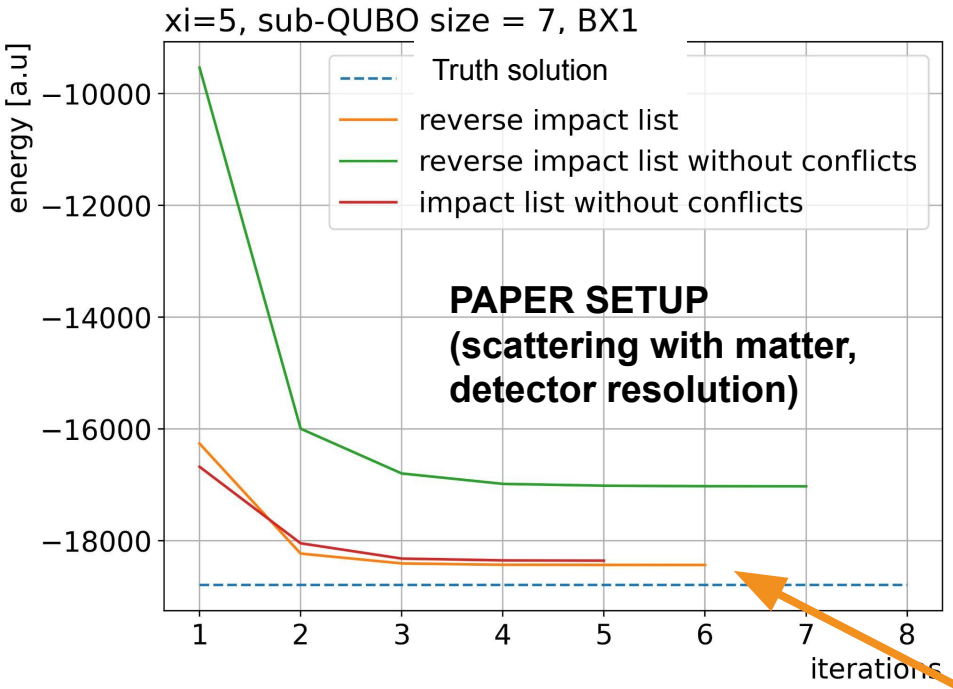
- data divided into 3709 sub-QUBOs
  - 3280 subQUBO matrices have no b_ij entries which means that triplets in these sub-QUBOs do not share any hit / have no connections/conflicts
  - 46 sub-QUBO matrices (~1.2%) have at least one b_ij entry ≠ 0
- hypothesis: sub-QUBO scaling in terms of efficiency / fake rate correlated to
  - the number of sub-QUBO matrices which have a b_ij entry ≠ 0
  - the average number of b_ij entry ≠ 0 per matrix

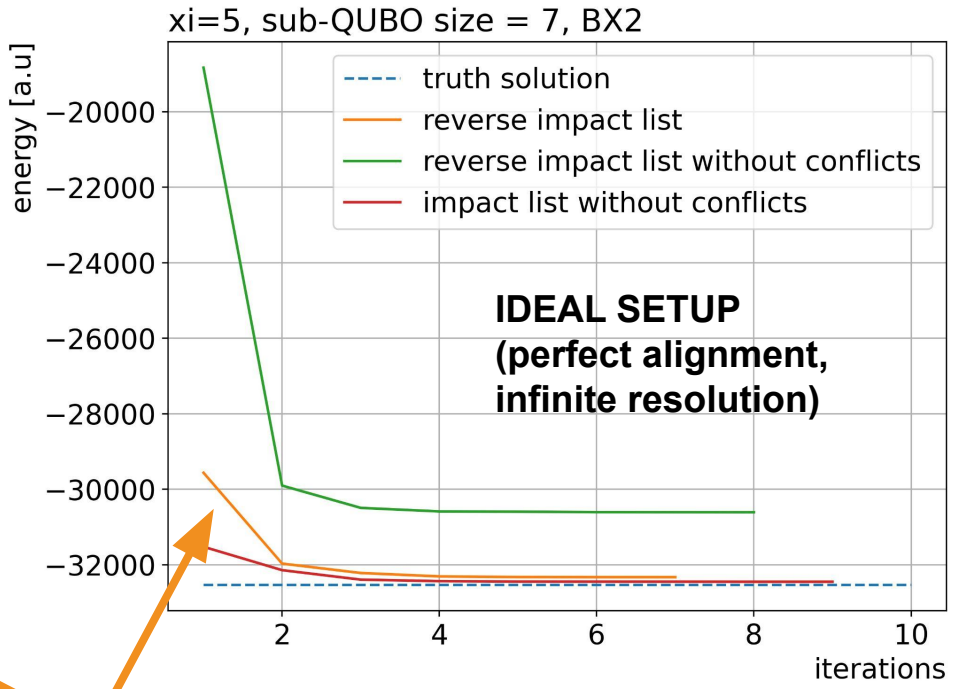
From David's talk

We know that the conflict terms dominate the solution of our QUBO

- Globally, because they are (the main) responsible for spreading the interacting triplets around in different subQUBOs
- Locally, because the subQUBO solution is also dominated by the linearised "out-of-subqubo" terms

Testing impact list variations





Reference paper results shown by orange line

Tested:

- Impact list based on Hamiltonian neglecting conflict terms (normal and inverted ordering)
- Alternative subQUBO formulation where “out-of-subqubo” conflicts are ignored (results are so much worse that they are off the scale)

Conflict weighting and QUBO coefficients

It is possible to alter the effect of conflicts in the impact list by changing the weight we assign them.

- Currently every conflict has weight +1

OPTIONS:

- Could make this an arbitrary constant and optimise its value
- The conflict weight could be a function of several quantities, e.g.:
  - Number of overlapping hits
  - Location of conflicting hits (i.e. which detector layer)

Similarly, the values of a_i and b_{ij} could be further optimised.

PROPOSAL: postpone studies. Mostly because at this point in time we have no indication that these would have a major impact on the results.

Impact list: wrap up 1

The impact list approaches similar to Bapst et al. hit their limits in LUXE's case because we have a way higher track density

- Conjecture: the problem might go away for a large enough sub-qubo size
  → study dependency of results with simulated annealing
  - Annabel has a working setup (thanks Tim for sharing!), however the results don't match the expectations (converge to lower energy levels than truth-based solution, etc..)
  - The overall solution quantum annealer finds (running on the full QUBO) is very close in efficiency to what our paper approach finds.
    The total track efficiency for the overall qubo xi5 of annealing is 97%, while the impact list approach with the files we used has 95% before ambiguity solving.
  - This confirms that the impact list still covers most of the solution and that the limiting factor is elsewhere (e.g. triplet level or hamiltonian formulation)

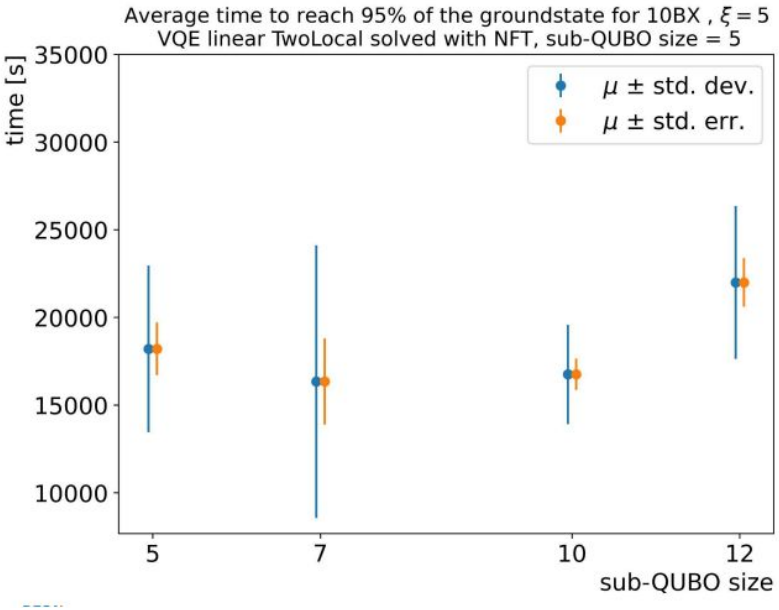
Impact list: wrap up

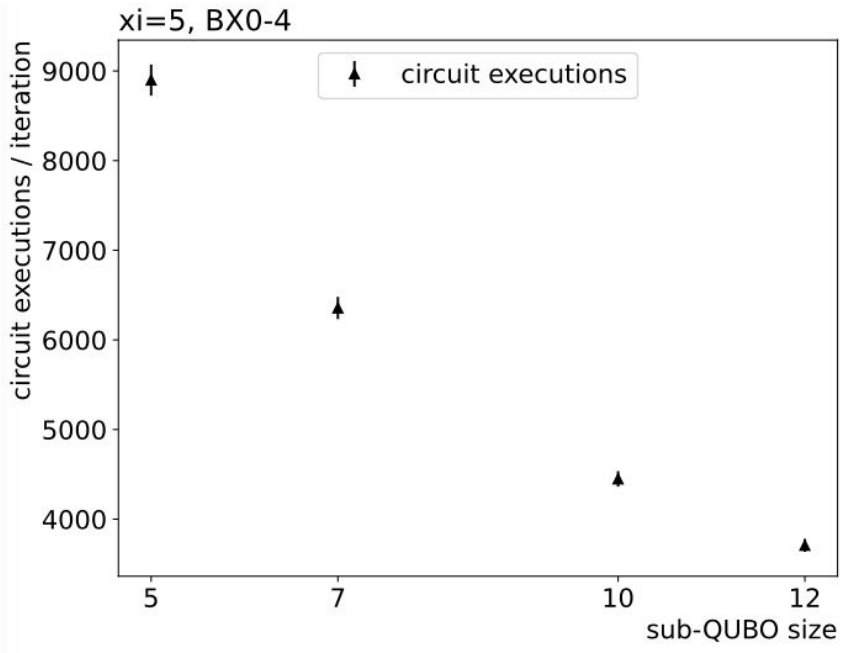
Left to study: Tobias' connectivity-based impacts, proximity-based subQUBO splitting, random subQUBO splitting (just as a reference)

PROPOSAL: discuss in the paper, in the context of the excellent performance already achieved, the limitations of the impact-list based approach with the results produced so far and highlight the future directions of research

- I personally believe that showing that these approaches can work and are competitive in terms of reconstruction performance is already a big result, we don't need to "win" every metric

Benchmarking



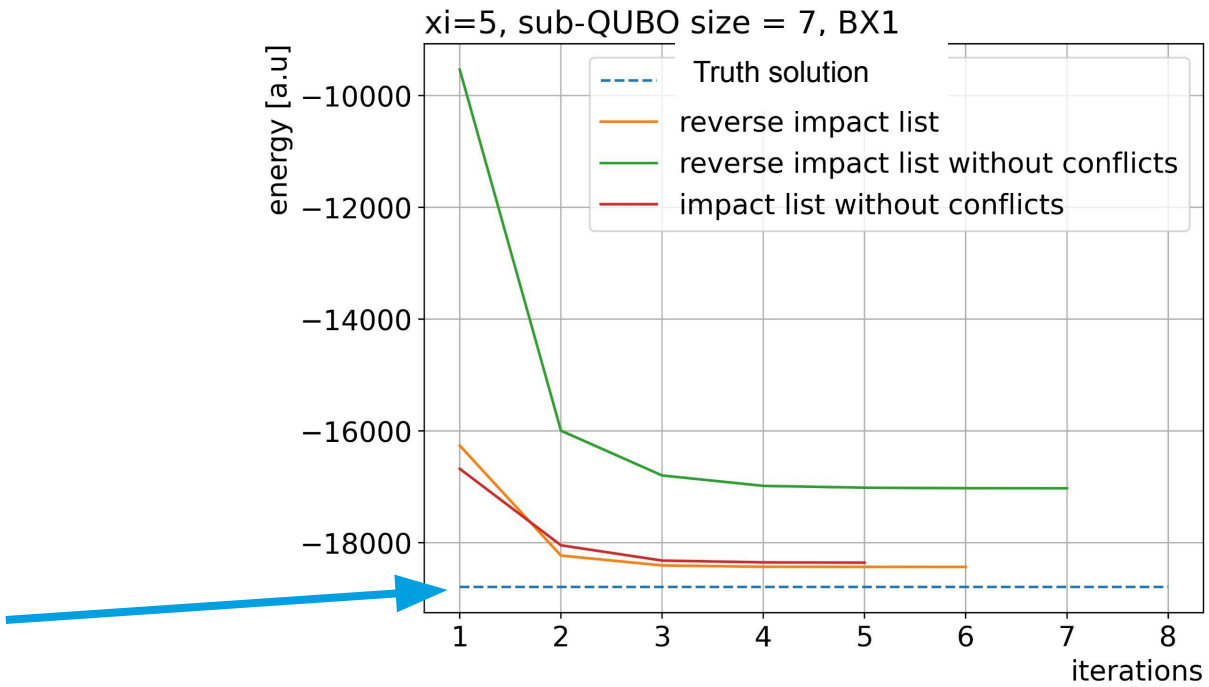


Decided to move from time-based benchmark to “number of circuit calls”

- Could show extrapolated behaviour assuming constant (or perfect) subQUBO solving efficiency to discuss scaling

PROPOSAL: this is the final result

Reference energy level or ground state?



We had some discussions about this line (previously referred to as “ground state”

- It is not! This is built by computing the energy that we get by selecting all and only the true triplets.
- Because of scattering and detector resolution, the ground state might actually be different (and sit at a higher, or lower, energy)

Do we care about knowing the true ground state? (I say: not really)

Minor: GNN results need optimisation

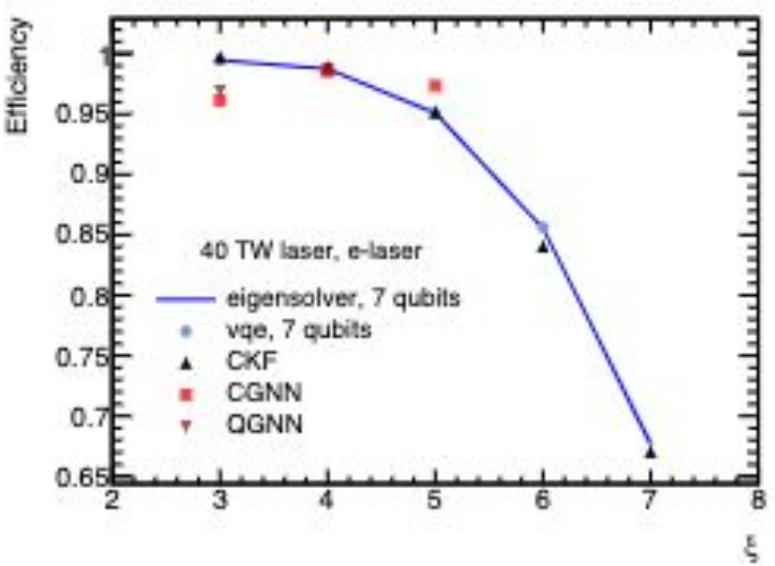
The current GNN results for xi>5 have a huge (600%) track duplication rate.

Also the efficiency at low xi is <1, which implies a sub-optimal training.

- The cut at 0.5 is not optimal?

Would like to see:

- ROC curve for xi=6
- “ROC” curve of efficiency vs duplication rate



PROPOSAL: Need to fix xi=3. Leave xi>5 out of the paper, optimise later.