AN EFFICIENT HIT FINDING ALGORITHM FOR BAIKAL-GVD MUON RECONSTRUCTION

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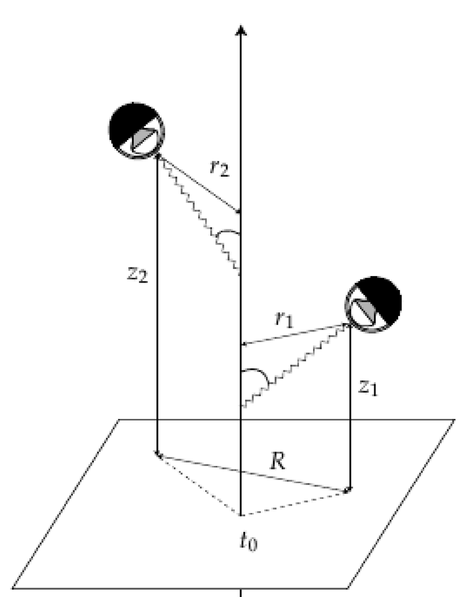
INTRODUCTION

We present an approach for selecting signal hits based on the ScanFit technique introduced in [1]. Similarly to ScanFit, for each event we assume a single muon track model and cover the sky with the lattice of possible track origin points corresponding to a considered track direction. A set of hits is selected for each direction using a directional causality test and the set that produces the optimal hit time based fit for a single track hypothesis is considred to be the signal, providing both noise suppression and a track prefit for reconstruction.

DIRECTIONAL CAUSALITY

In this work we heavily use a directional causality criterion from [1]. For a predefined track direction and a pair of causaly related hits i and j, the following conditions must be true:



$$|\Delta r_{i,j}| < R$$

$$\Delta z_{i,j} - kR - w \leq c\Delta t_{i,j} \leq \Delta z_{i,j} + kR + w$$

Here, w is a tunable parameter for hit timing uncertainty and k is a constant depending only on the refraction index of the observed medium. Note that the directional causality relies only track direction, which makes the scanning part of the primary algorithm possible.

REFERENCES

References

[1] Ronald Bruijn et al. *The Antares Neutrino Telescope: Performance studies and analysis of first data*. Universiteit van Amsterdam [Host], 2008.

[2] VA Allakhverdyan et al. Measuring muon tracks in baikal-gvd using a fast reconstruction algorithm. *arXiv preprint arXiv:2106.06288*, 2021.

PERFORMANCE

Sample	Average purity	Average efficiency
Atmospheric neutrino sample (for algorithm from [2])	0.99	0.5
Atmospheric neutrino sample	0.95	0.95
High energy (E^{-2}) neutrino sample	0.98	0.74
High energy (E^{-2}) neutrino sample (at least 8 track hits)	0.98	0.89
Multicluster atmospheric neutrino sample	0.98	0.87
Multicluster atmospheric neutrino sample (at least 8 track hits)	0.98	0.9

Table 1: Algorithm performance for various samples

ALGORITHM DESCRIPTION

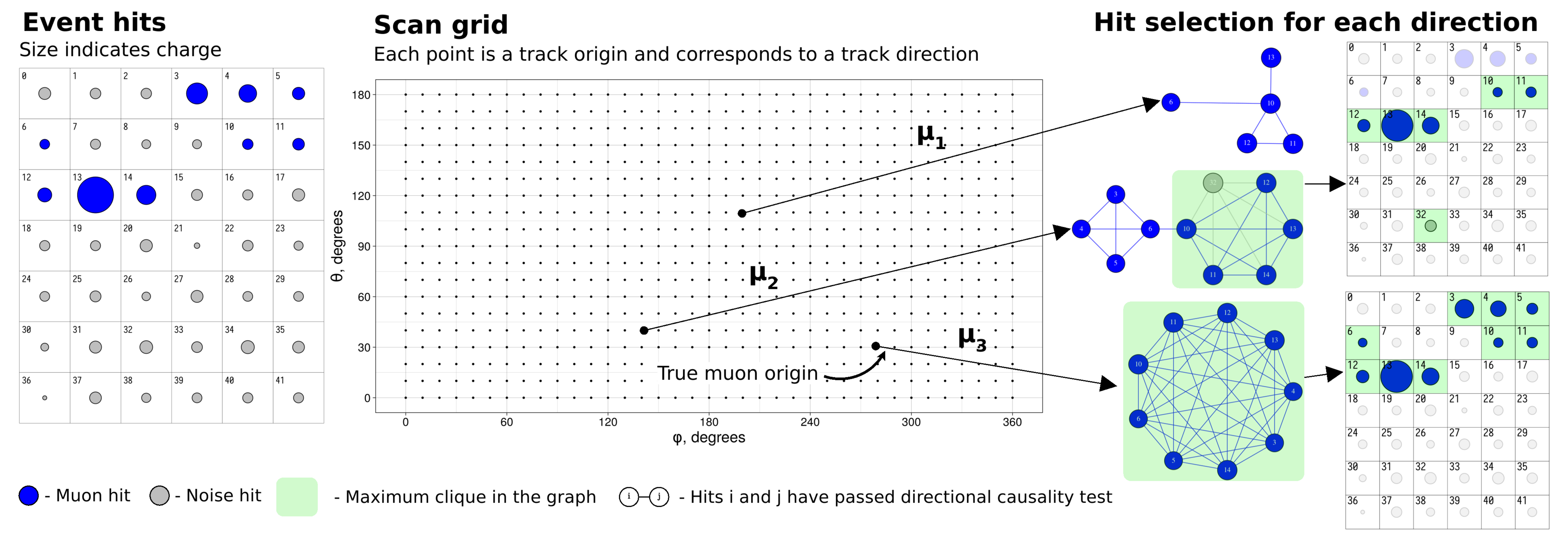


Figure 1: The example of the scanning step for 3 considered track directions of an upgoing muon event with the minimal clique size set to 6 is presented on Figure 1. Three scan grid directions are considered. μ_1 produces a causality graph with the maximum clique of size 3 and is ignored. μ_2 produces a graph with two maximal cliques and only the largest one is considered. μ_3 is close to the true track direction and produces a graph with only one clique that contains all signal hits. Finally, two cliques pass to the clique selection stage: a single clique from μ_3 and the largest clique from μ_2.

1. **Prefilter** A set of hits is preselected for processing. Processing time in the following stages increases quadratically with the number of hits, so at this stage we want to remove easily identifiable noise.
2. **Initialization** We select a set of directions in the sky. Currently, a rectangular grid in spherical coordinates.
3. **Scan** For each direction in the grid a subset of hits is selected, based on the assumption that coordinates of the direction correspond to the direction of the particle. First, we construct a causality graph of the event - a graph where each hit is represented by a vertex and two vertices share an edge if the corresponding hits satisfy causality conditions as described in [2]. The causality parameters are relaxed to avoid rejecting signal hits. Next, we use the Bron-Kerbosch algorithm to find the maximal cliques in the causality graph - the largest subsets of vertices where all vertices are connected to each other and only select hits from largest clique.
4. **Clique selection** All hits in cliques are fitted to the corresponding track model. Cliques smaller then the largest or second-largest ones are ignored.
5. **Output** The output is the 1) the track prefit corresponding to the direction with minimum M-estimator and 2) hits selected for this vertex.

SCAN EXAMPLES

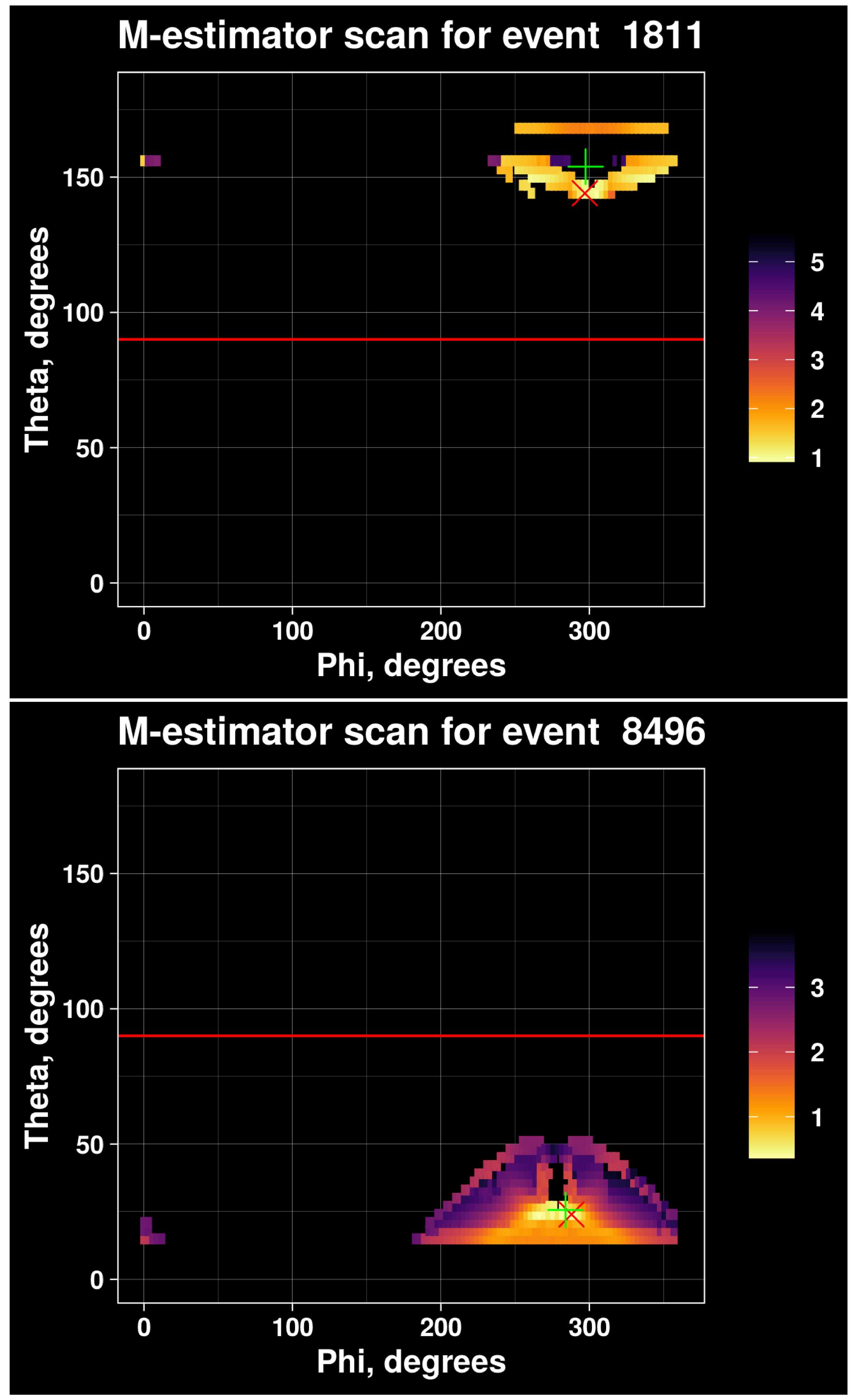


Figure 2: Event scan examples for a muon bundle (top), and an upgoing muon (bottom). Each pixel corresponds to a scanned direction that passed the clique selection. Green cross corresponds to the true event origin, red cross to the selected direction.

CONCLUSION

Our approach alters key steps in the previous work by considering pairwise causal relationships between PMT hits as an undirected graph and assuming that signal hits should form fully connected subgraphs (cliques) in it. The new approach has demonstrated a 95% purity and 95% efficiency for an atmospheric neutrino sample, almost two-fold inrease in efficiency compared to the hit selection algorithm previously used in Baikal-GVD.