

FASER ν reconstruction

T1-FASER ν subgroup

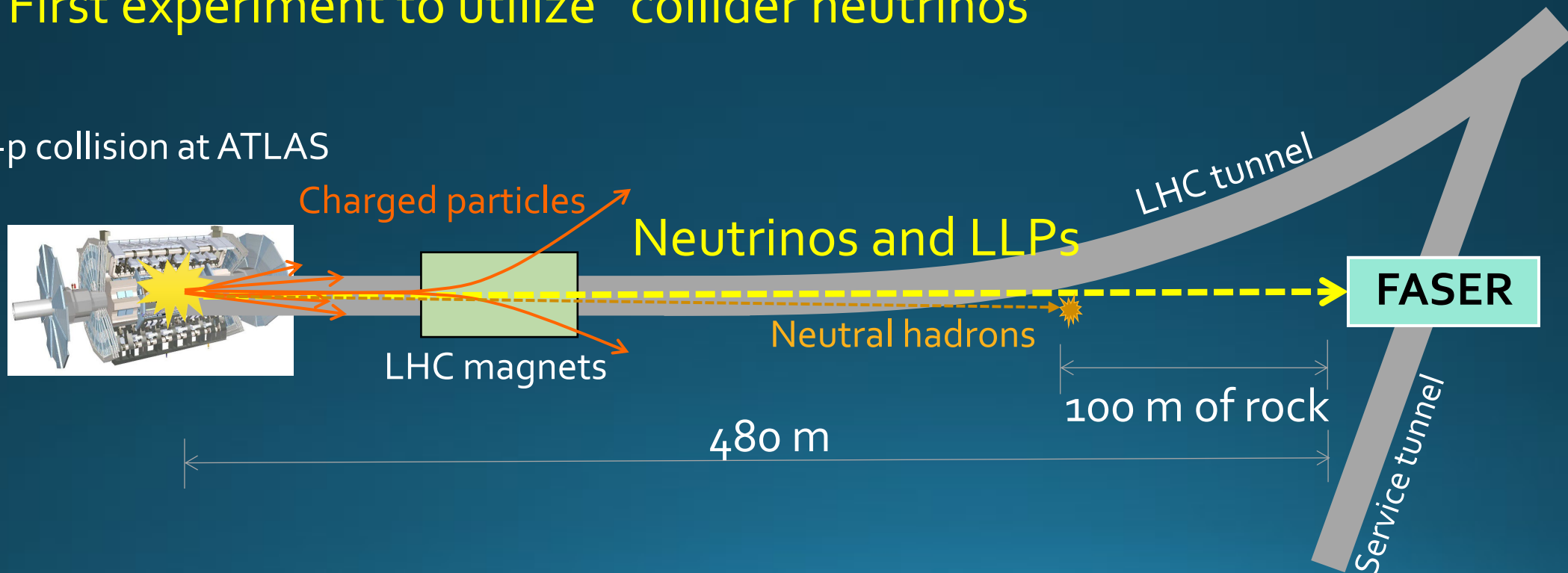
The FASER experiment

FORWARD SEARCH EXPERIMENT AT THE LHC

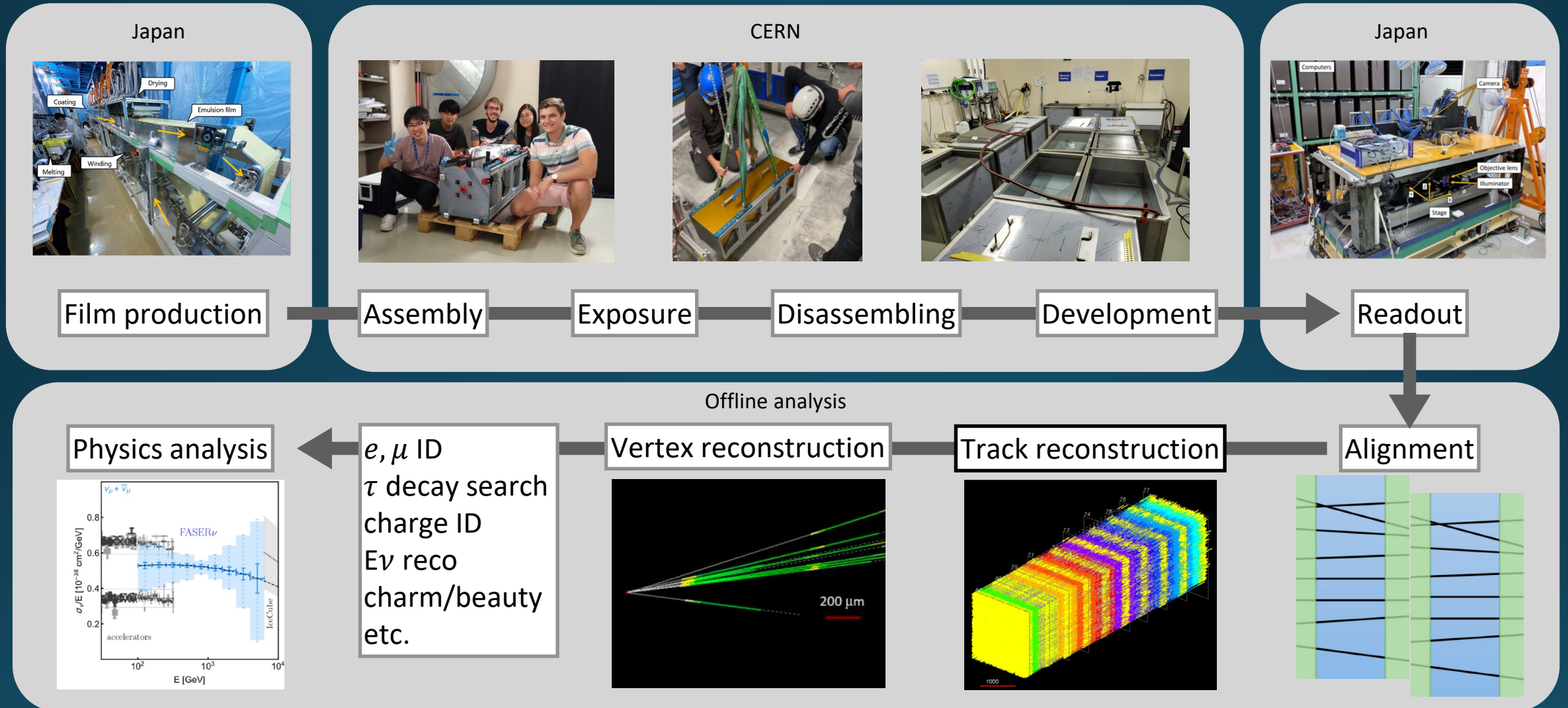
FASER TP [arXiv:1812.09139](https://arxiv.org/abs/1812.09139),
FASER ν [Eur. Phys. J. C \(2020\) 80: 61](https://arxiv.org/abs/2005.04861)
FASER web page: <https://faser.web.cern.ch/>

- Targets neutrinos (and μ) and long-lived BSM particles (e.g. A' , ALPs)
- First experiment to utilize “collider neutrinos”

p-p collision at ATLAS

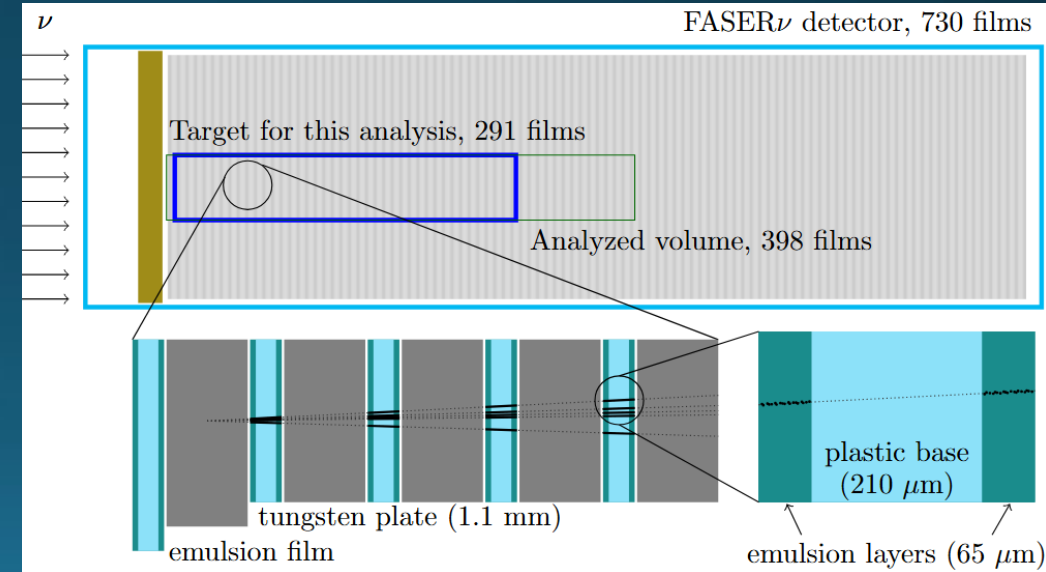
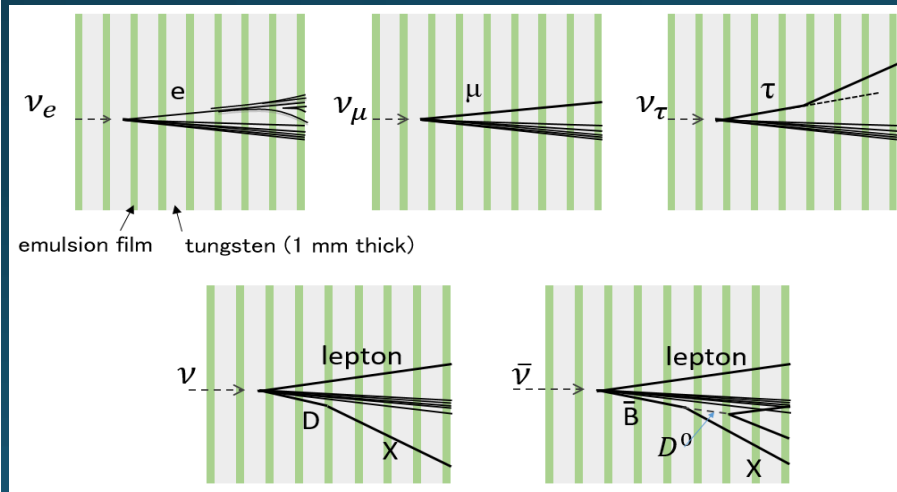
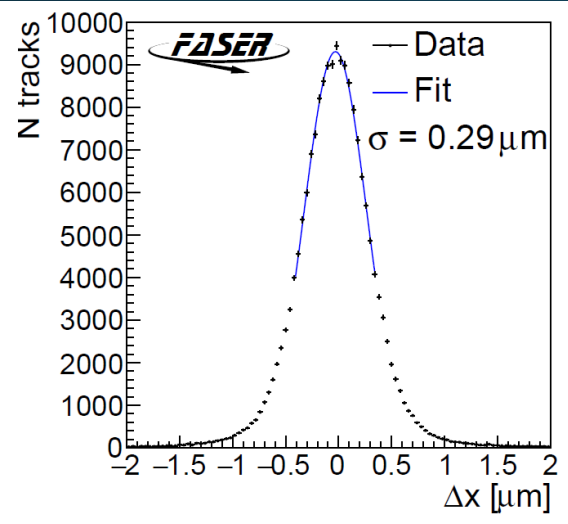
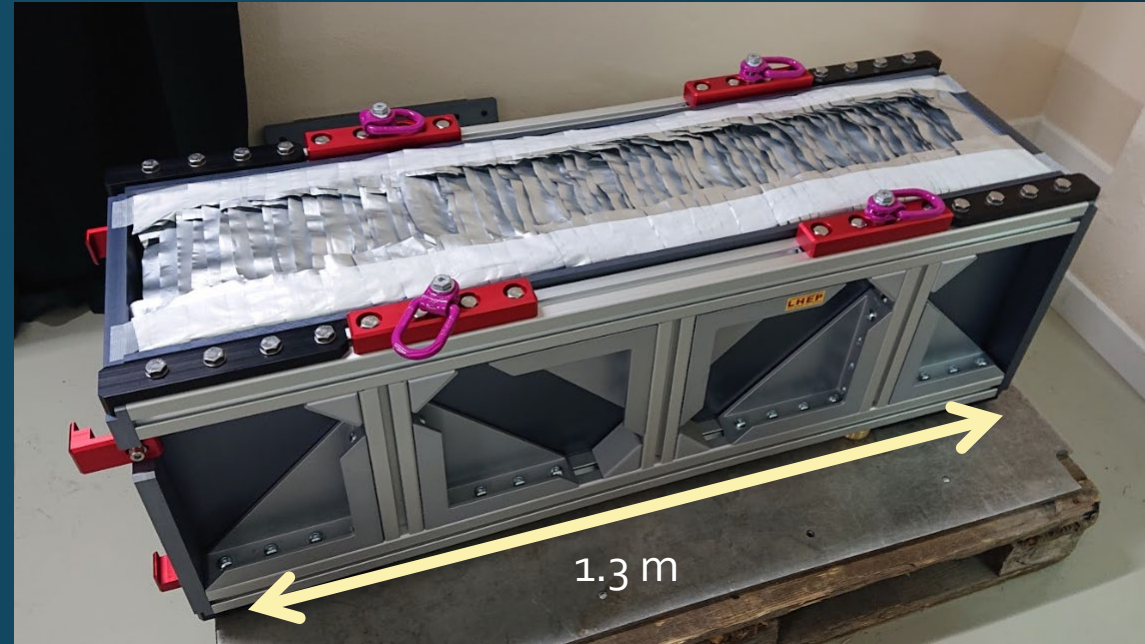


FASER ν steps, 3 detectors per year



FASER ν and current sample

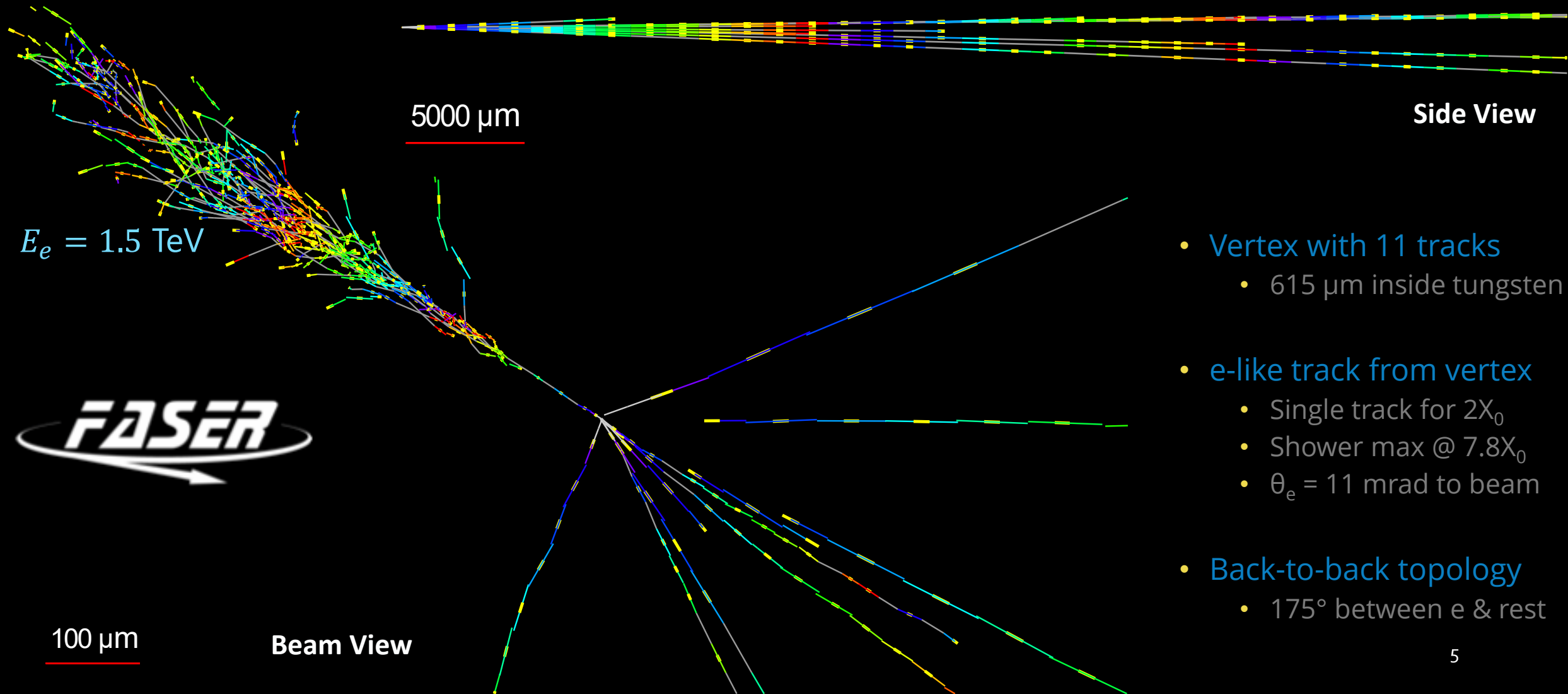
- Emulsion/tungsten neutrino detector
 - 730 emulsion films ~ an exa-channel detector
 - Target mass of **1.1 tons** ($8 \lambda_{int}$, $220X_0$)
 - Typical position resolution, **300 nm**
- Data set for the published result:



TeV electron neutrino observation in FASERv

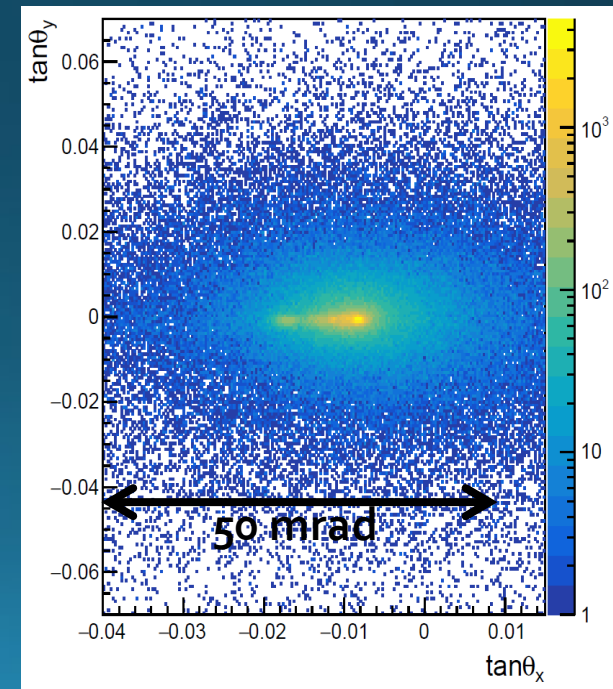
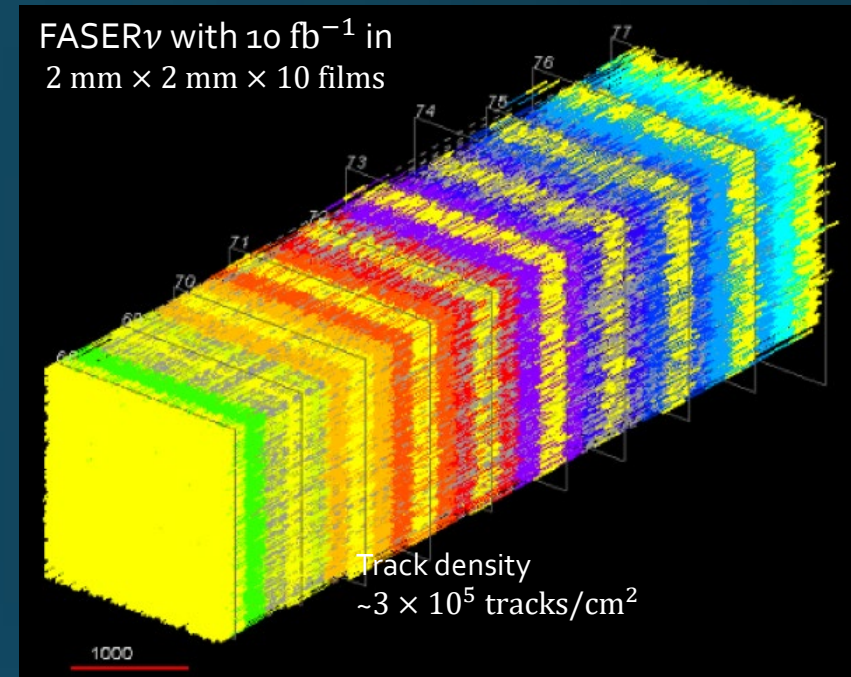
ν_e CC event, “Pika- ν ” event

Enjoy an interactive 3D display [here!](#)



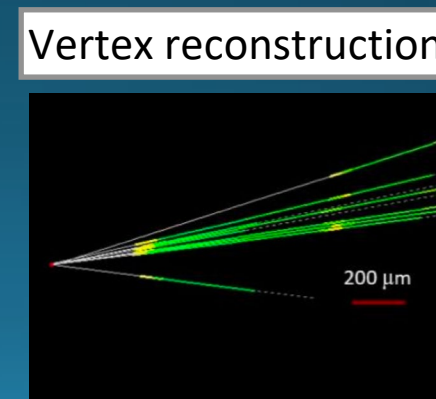
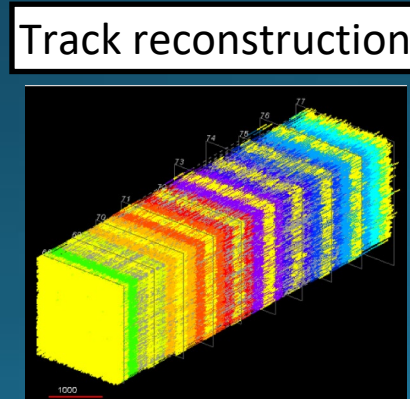
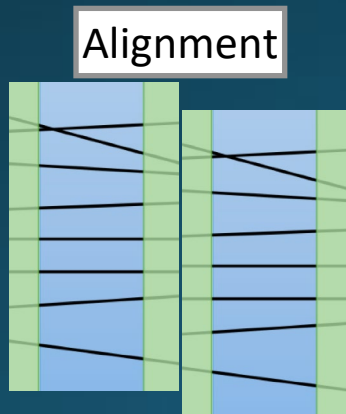
Challenges and problems

- We have $O(0.1 - 1)$ Hz of background muons
- FASER ν doesn't have time info $\rightarrow$ **Pile up of 10^8 events!**
- High occupancy in the detector
 - 3×10^5 tracks/cm (10 fb^{-1})
 - 10^6 tracks/cm (30 fb^{-1}) $\rightarrow \frac{1 \text{ tracks}}{10 \mu\text{m} \times 10 \mu\text{m}}!$
 - Most of tracks fall **in a same angular space**
 - $\rightarrow$ makes difficult to differentiate by angle



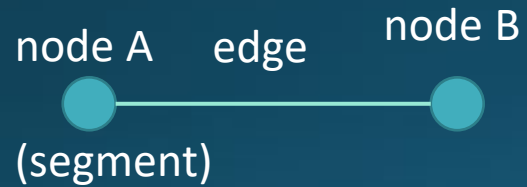
Nature of data, input/output

- Our “**hit**” is a track segment measured in each emulsion film
- Each segment is represented by a **5D vector**;
 $(x, y, z, \tan\theta_x, \tan\theta_y) + (\text{quality parameters})$
- Segments are linked across films to reconstructed particle tracks
- Output: **groups (or lists) of segments** belonging to each reconstructed track



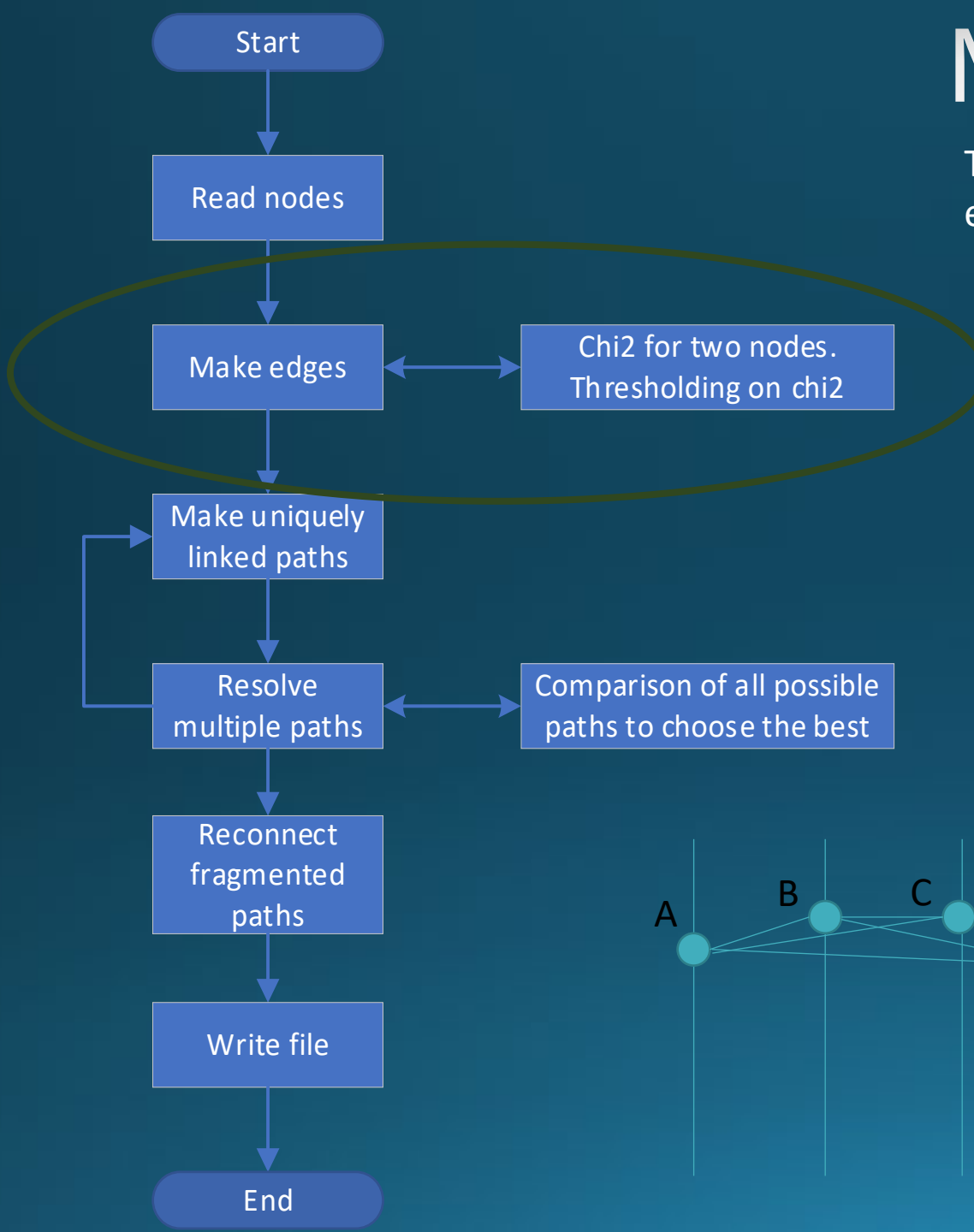
Tracking algorithm

- Terms
 - node : track segment on a film
 - link : collection of nodes
 - edge : link with 2 nodes
 - path : link with ≥ 2 nodes

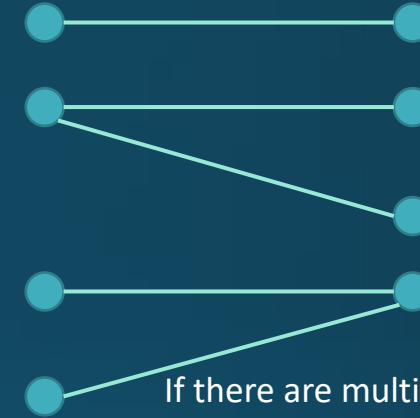


Make edges

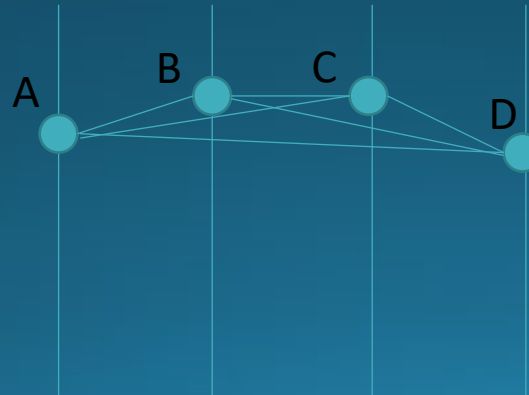
Take two nodes, calculate chi2 to be an edge. If it is accepted, make an edge.



edge (p=0.99999)



If there are multiple edges to a single node, compare chi2. If an edge has delta-chi2 (delta from minimum chi2) more than an threshold (p=0.9), reject the edge.



Edges are searched within 4 plates.

There will be

A-B, A-C, A-D

B-C, B-D

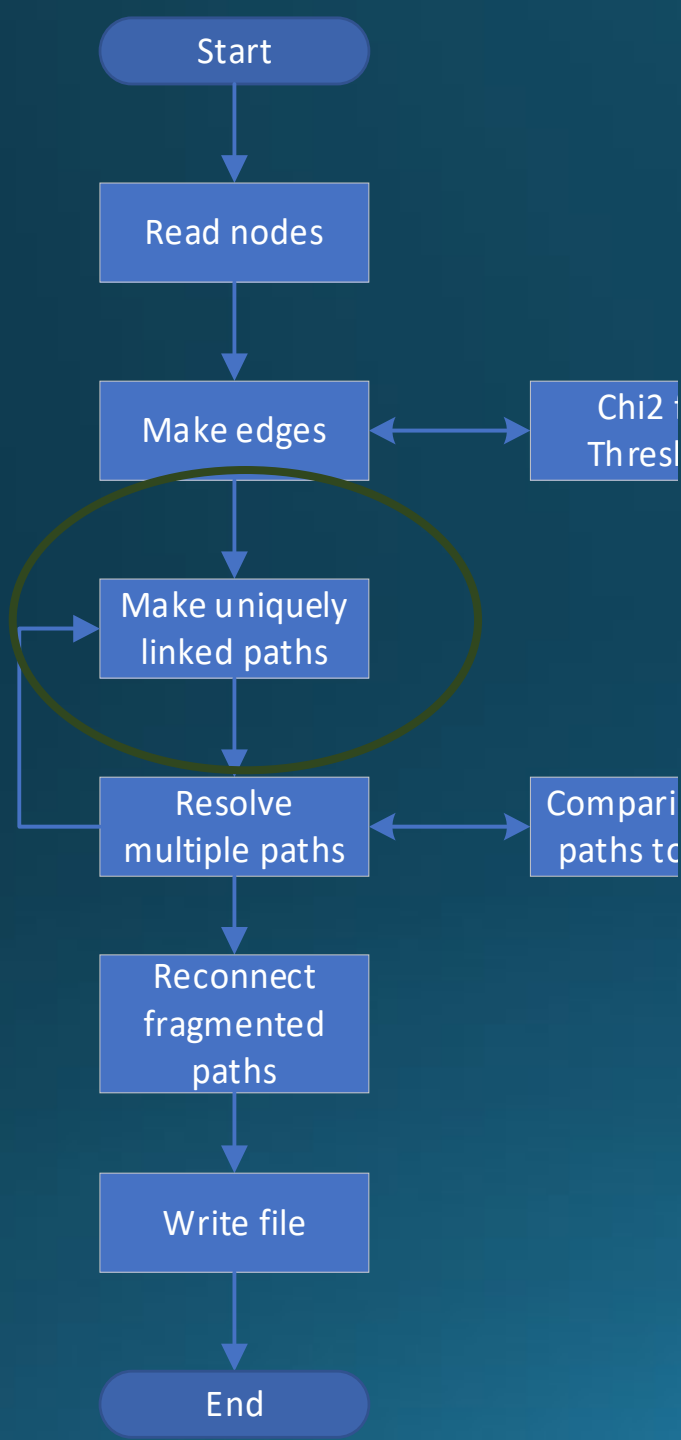
C-D

Think 3 nodes links

A-B-C, A-C is included in A-B-C,

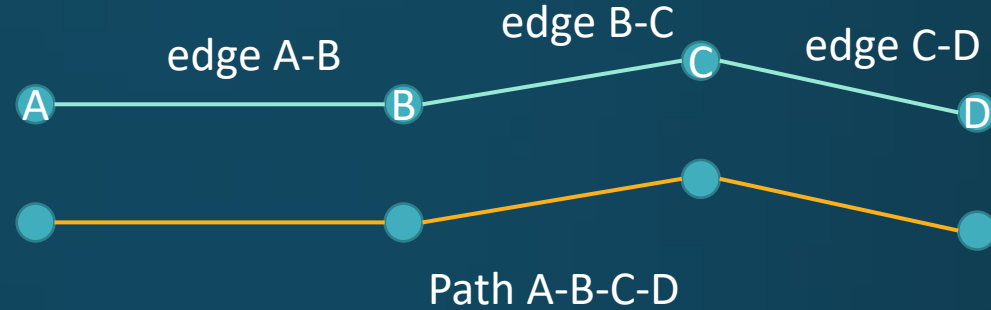
remove A-C. A-D is included in A-B-

D, remove A-D

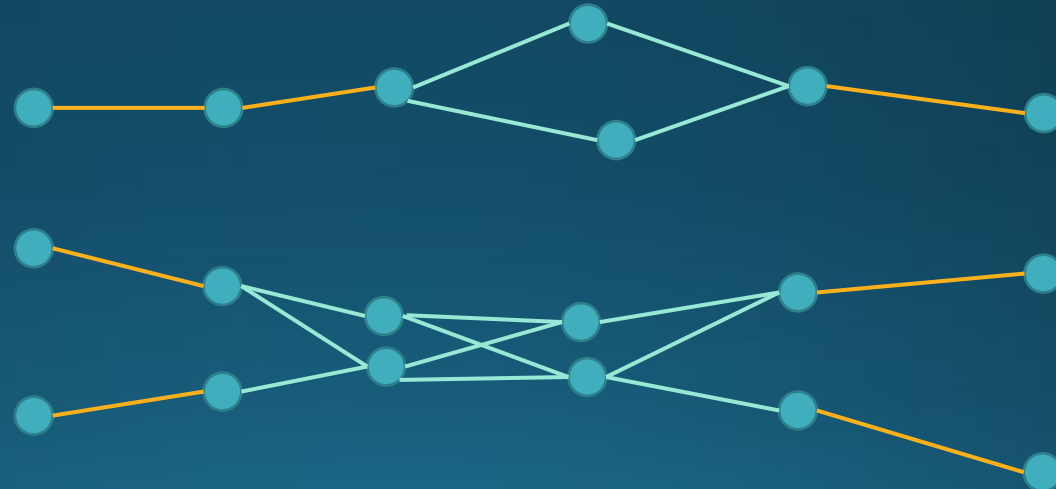


Make unique paths

Follow edges, if there is not branches, promote to "paths".

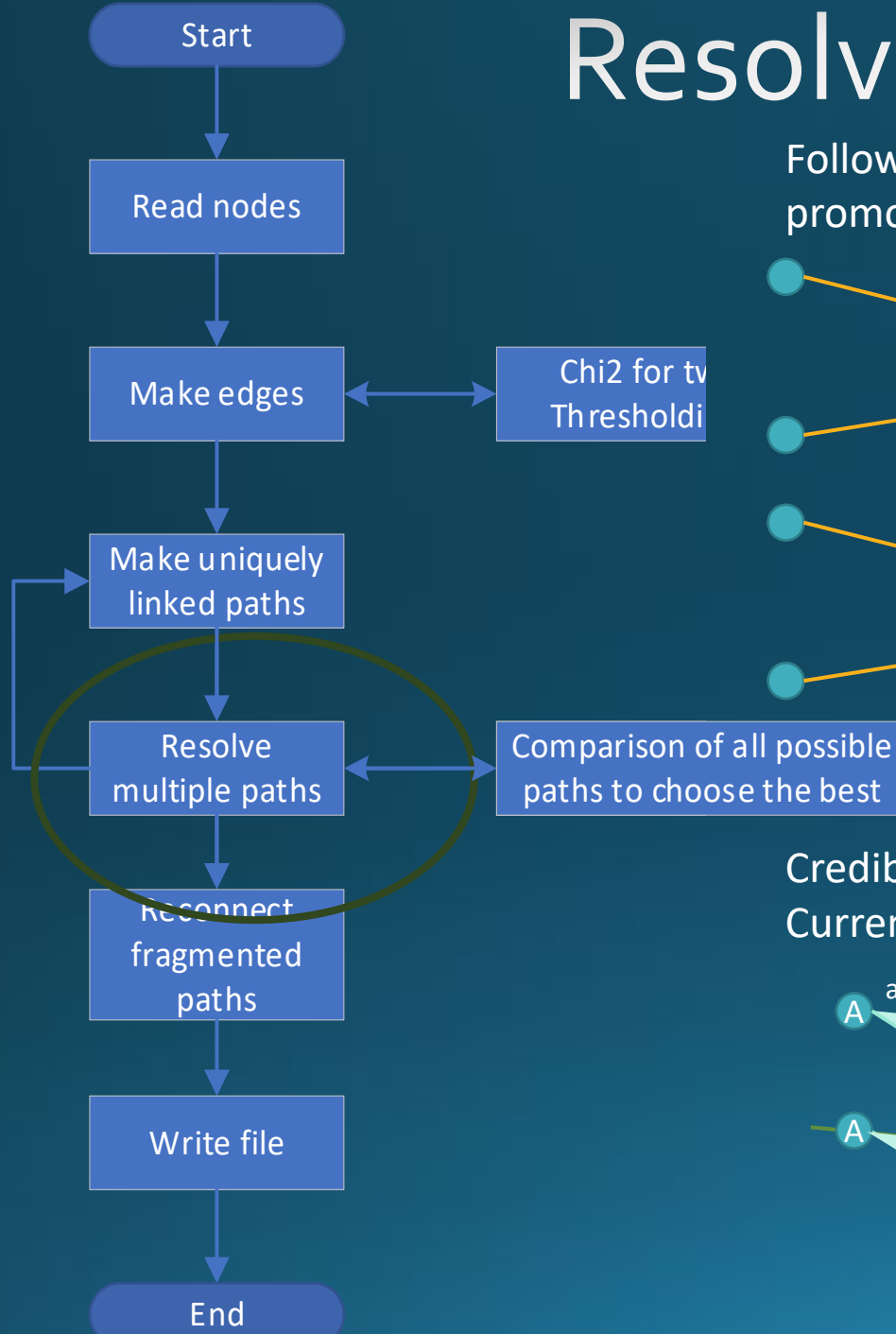


If there are branches, stop making unique path.

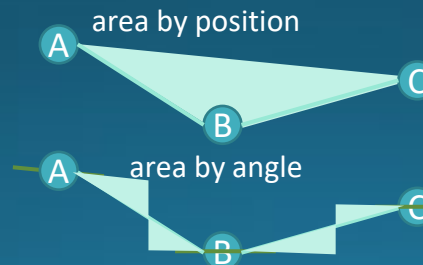


Resolve multiple paths

Follow edges, if there is not branches, promote to “paths”.



Credibility of all the paths is evaluated by a function. Current implementation is based on areas.

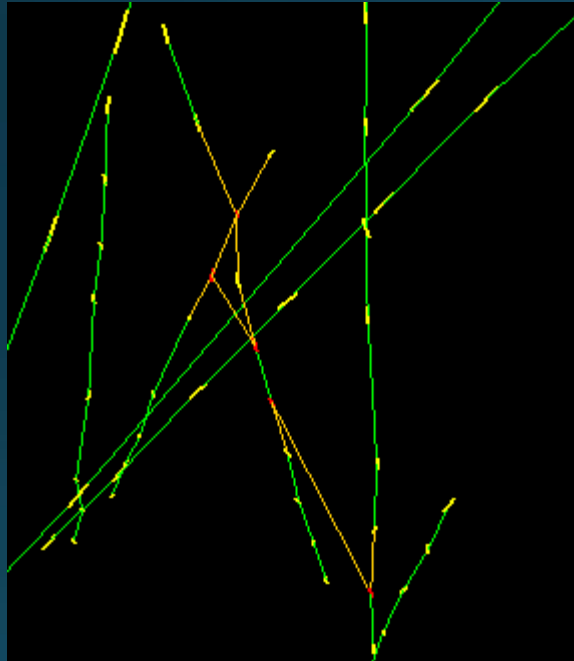


$$|AB \times AC| / 2$$

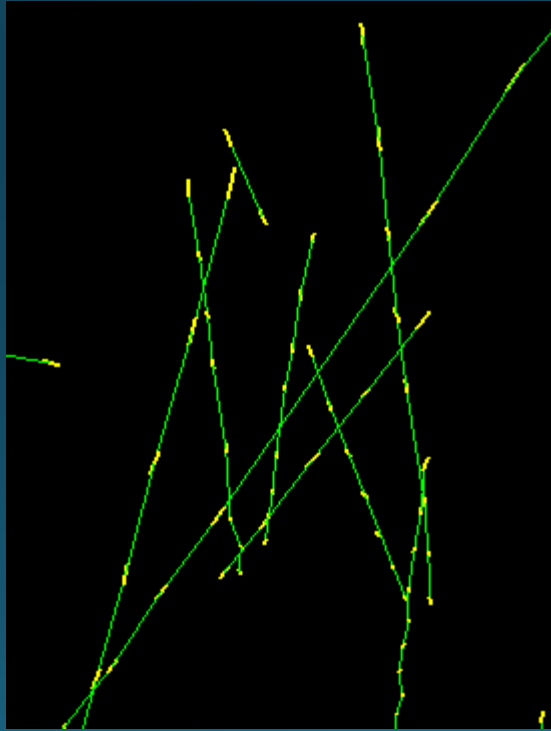
$$\sum \delta \theta_i \Delta z_i / 2$$

Smaller area, better path.

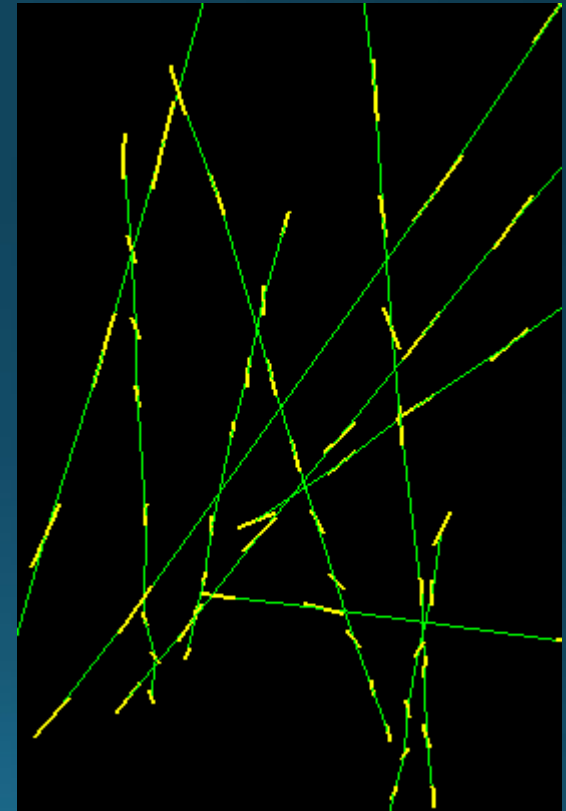
Examples



Multi connected edges (orange)
Unique paths (green)

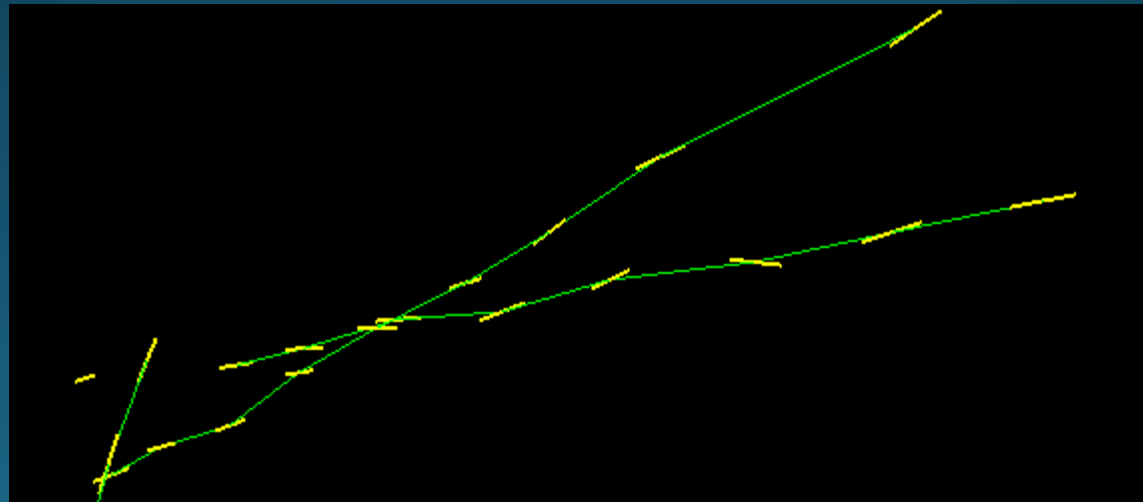
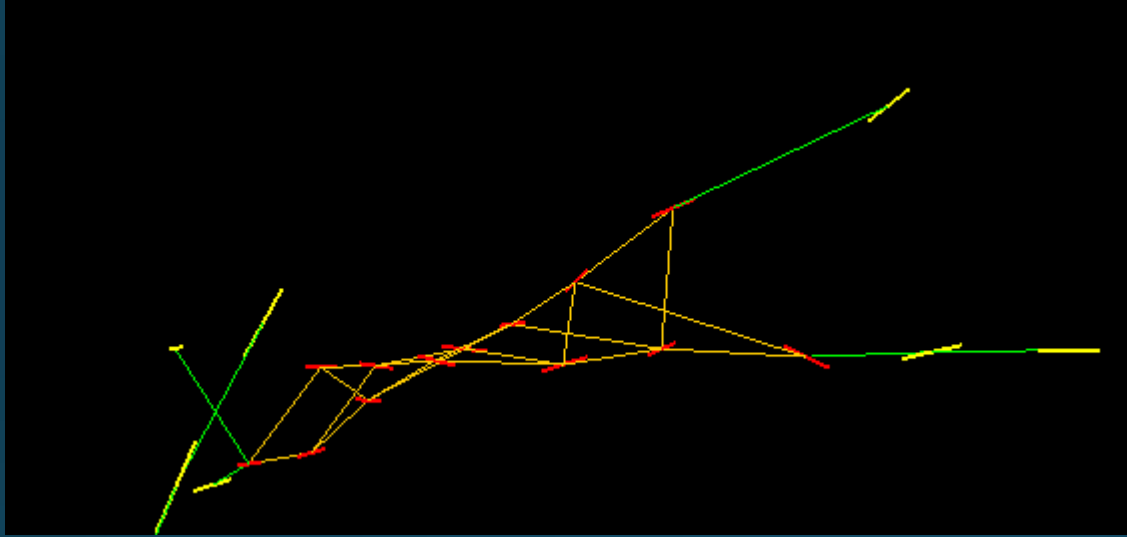


After resolving multiple connection

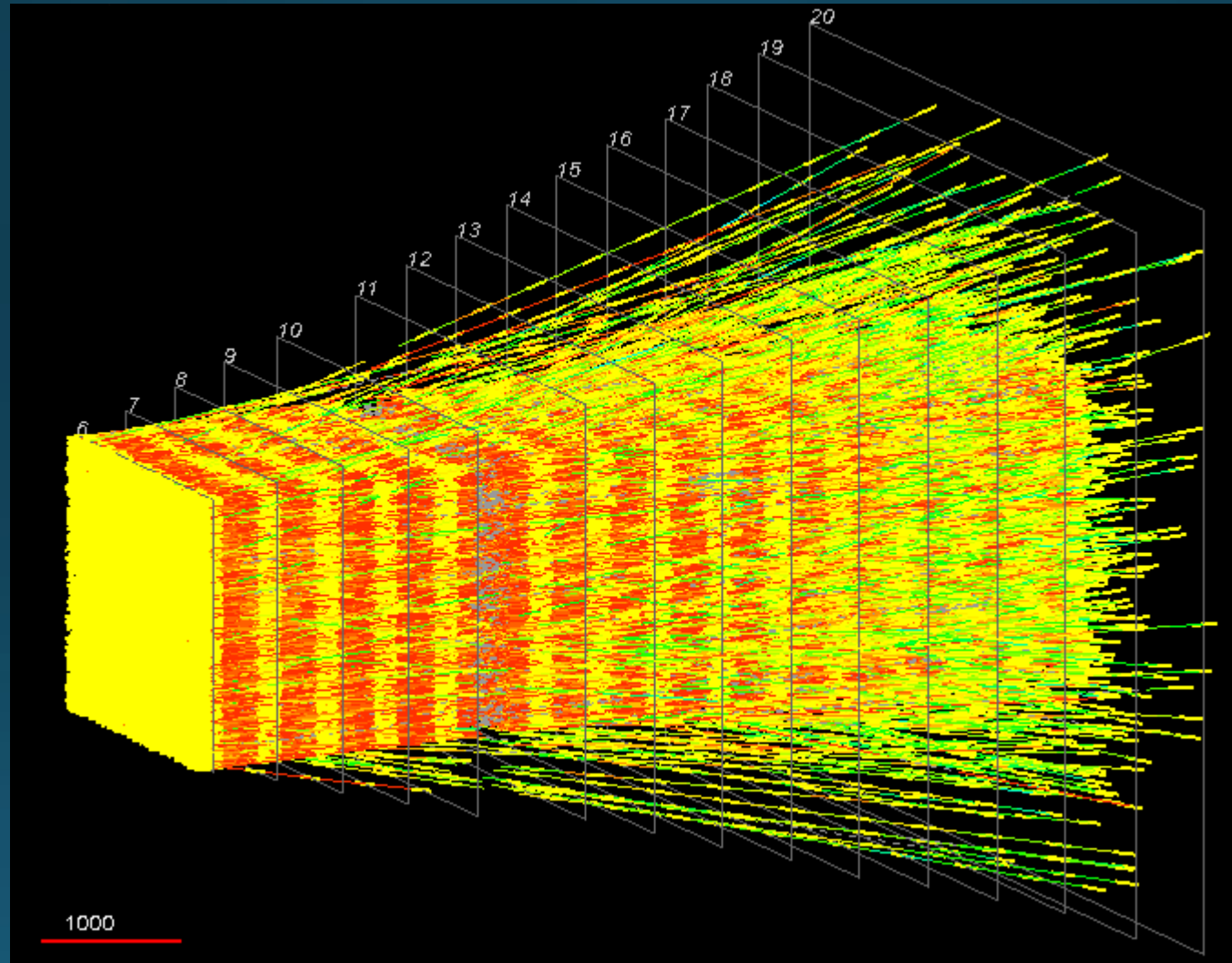


After reconnection of paths

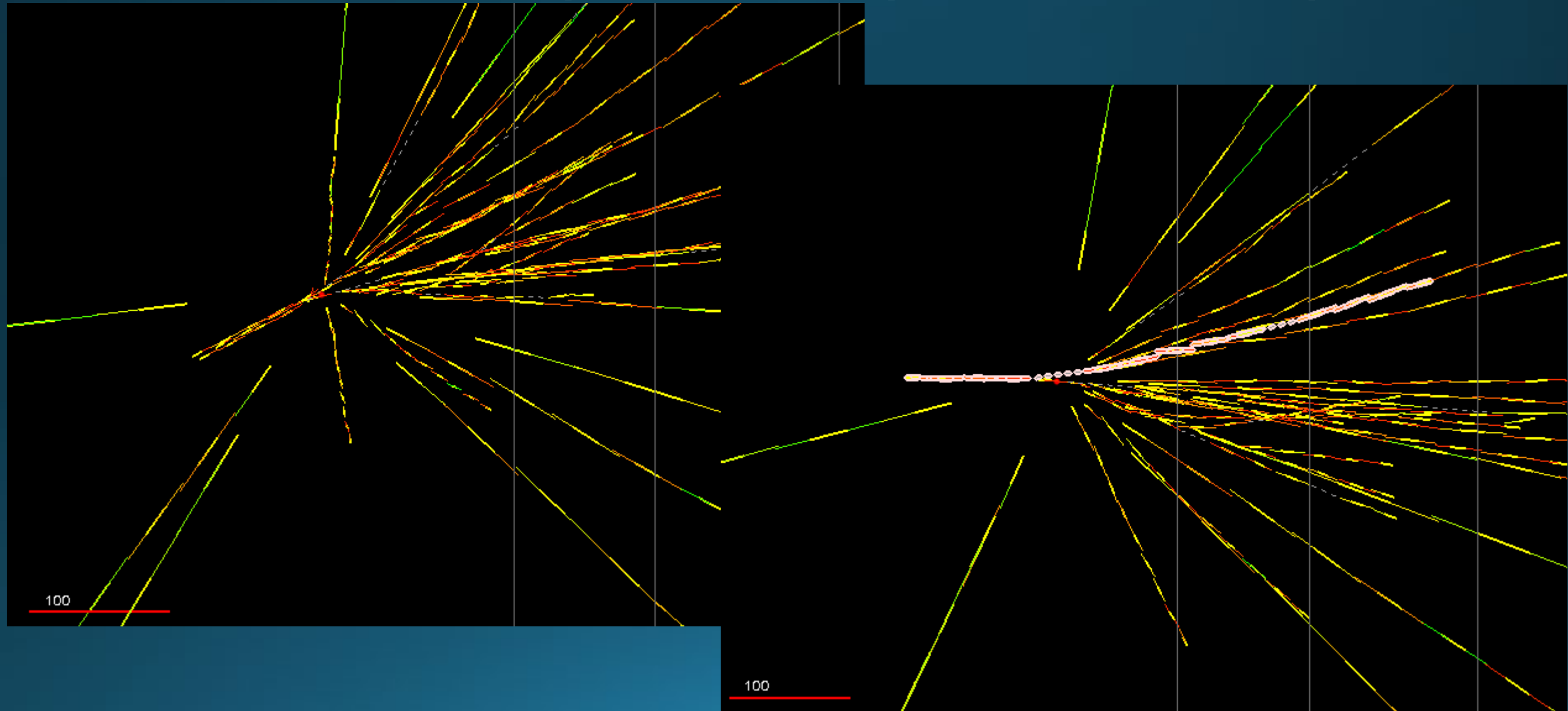
Examples



Reconstructed tracks (DsTau proton data)

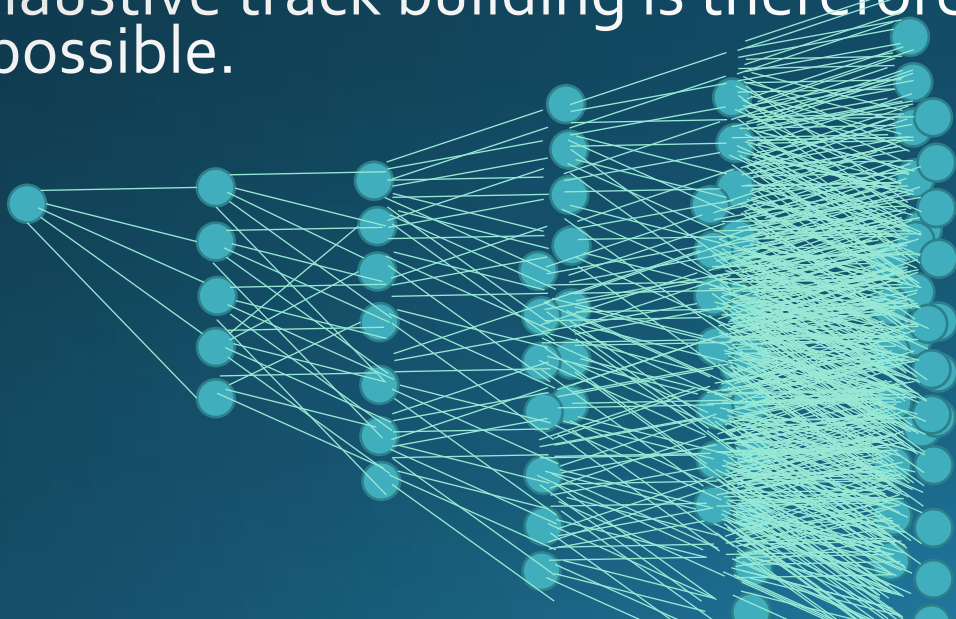


Vertex with parents (proton sample)



Simple problem: Combinatorial Explosion

- It works at low density $< 5 \times 10^5$ tracks/cm²
- For high density $\simeq 10^6$ tracks/cm², combinations explode
 - Each node is connected to ~ 5 nodes, 30 plates $\rightarrow 5^{30}$ possible combinations
- Exhaustive track building is therefore impossible.



- Current approach
 - Stop the search when excessive branching persists for ≥ 6 layers.
 - Tracks are fragmented and reconnected later.
- Can AI find the right path without exploring them all?
 - Score candidate branches using local and accumulated track information.
 - Keep only the most promising branches while propagating the track.
 - GNN-based sequential pruning?
 - Other architectures exploiting longer-range information? Transformer / Attention...

What are the practical difficulties?

- **Computational cost**

- Even the current simple χ^2 -based tracking is computationally expensive.
- GNN-based approaches could further increase the computing cost and may become impractical at full scale.

- **TeV-energy muons travel almost parallel to each other**

- Two tracks can remain only **$\sim 1 \mu\text{m}$ apart over 10 cm (~ 100 layers)**
- One track may be lost already at the **hit-recognition stage**, in addition to the combinatorial ambiguity

- **Robustness to changing data conditions**

- Models can be trained on MC, but track and background densities vary significantly between data samples.
- If an **electromagnetic shower overlaps**, the local track density can increase dramatically

→ Can AI-based tracking remain stable under changing conditions?

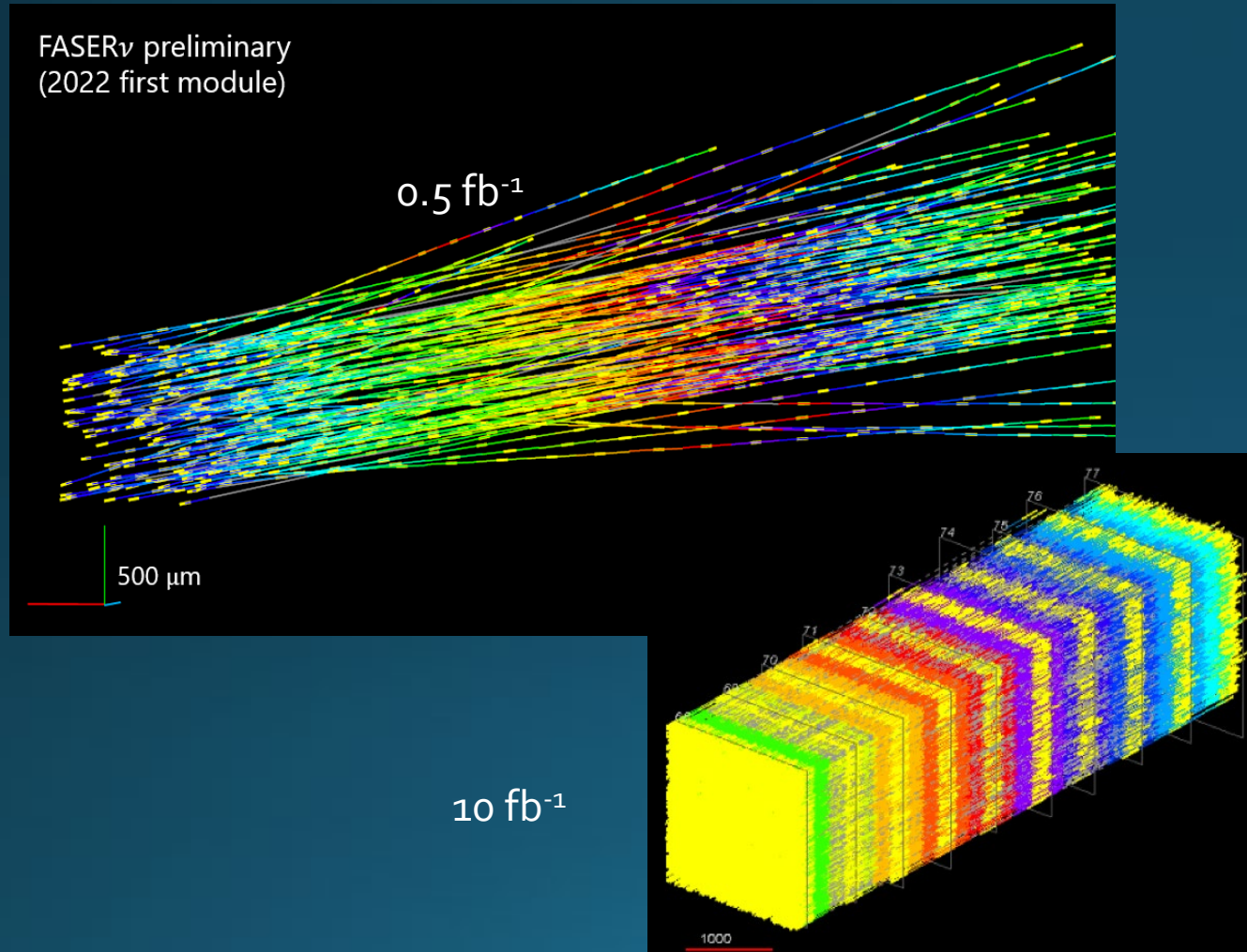
Help us!

- We are still at an early stage of applying ML to emulsion data processing
- There are many opportunities for ML to make a real impact
- Your expertise and collaboration are essential!

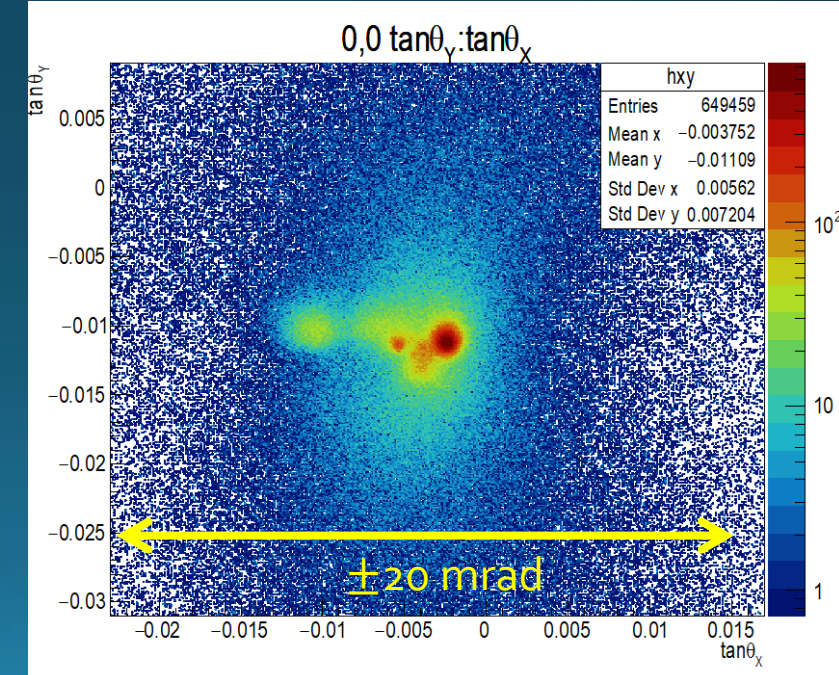
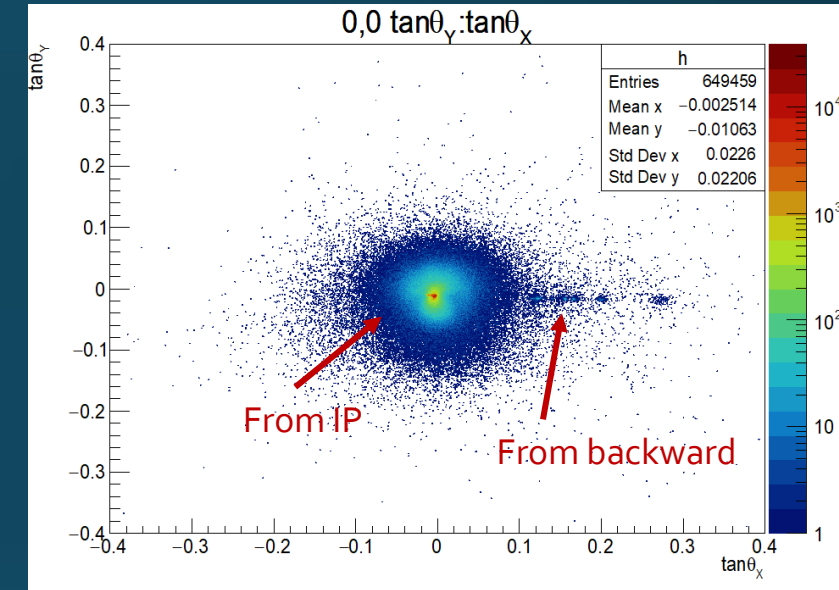
Backup

Muons at FASER site

- Muons brings rich info to validate beamline simulation
- Eventually we could validate hadron production models at p - p collisions



Angular distribution (Data)



FASER
preliminary

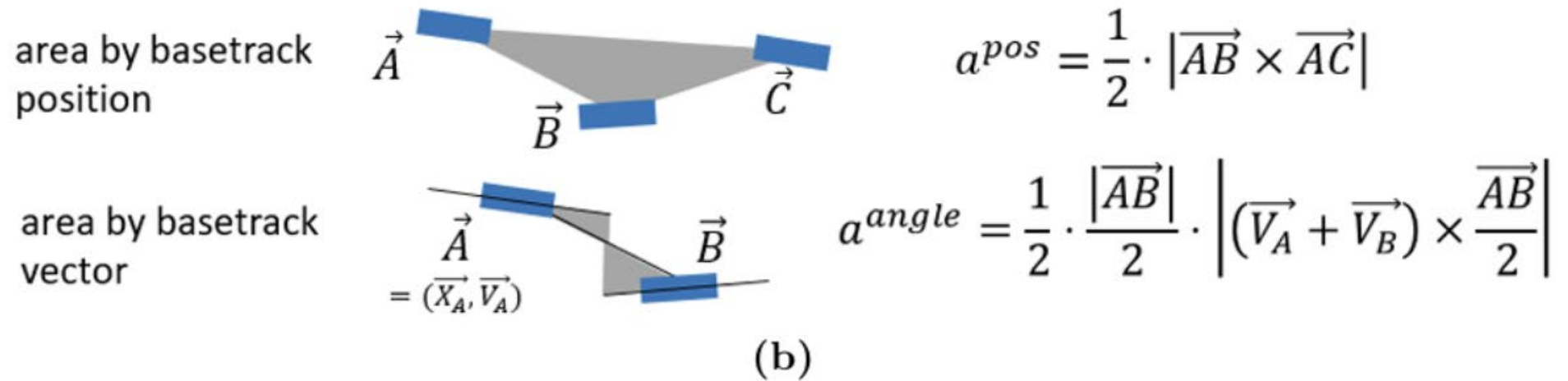
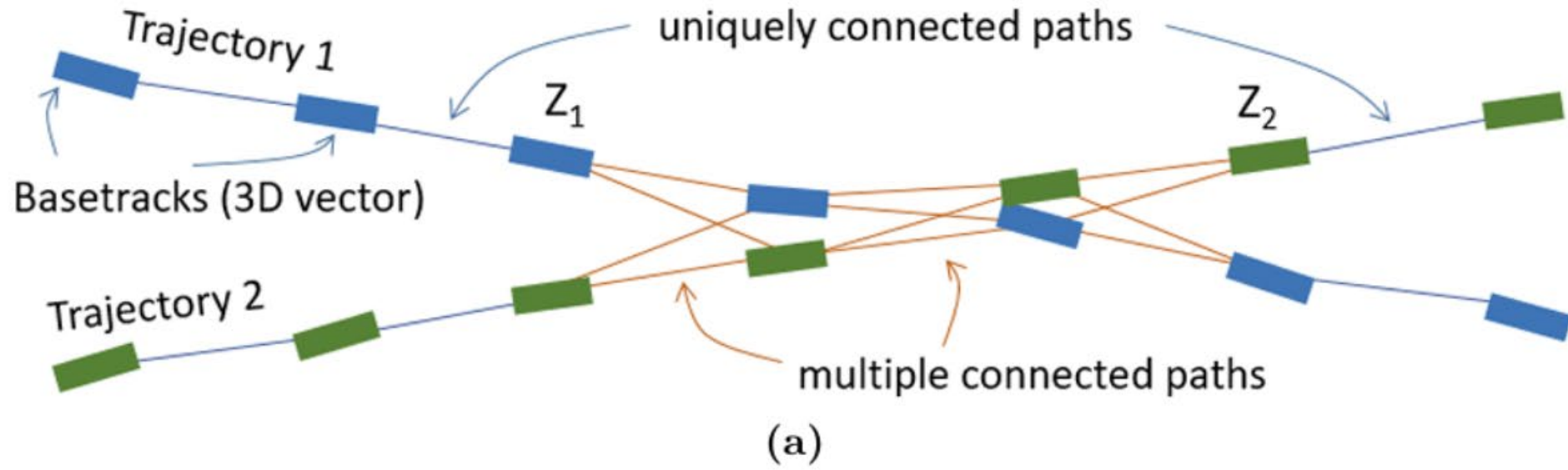


Figure 21. (a) Two tracks come closer and there are multiple possibilities in finding paths. (b) Areas made by basetracks, that are used to select the best possible paths.

Electromagnetic showers

