SKYNET vertex reconstruction

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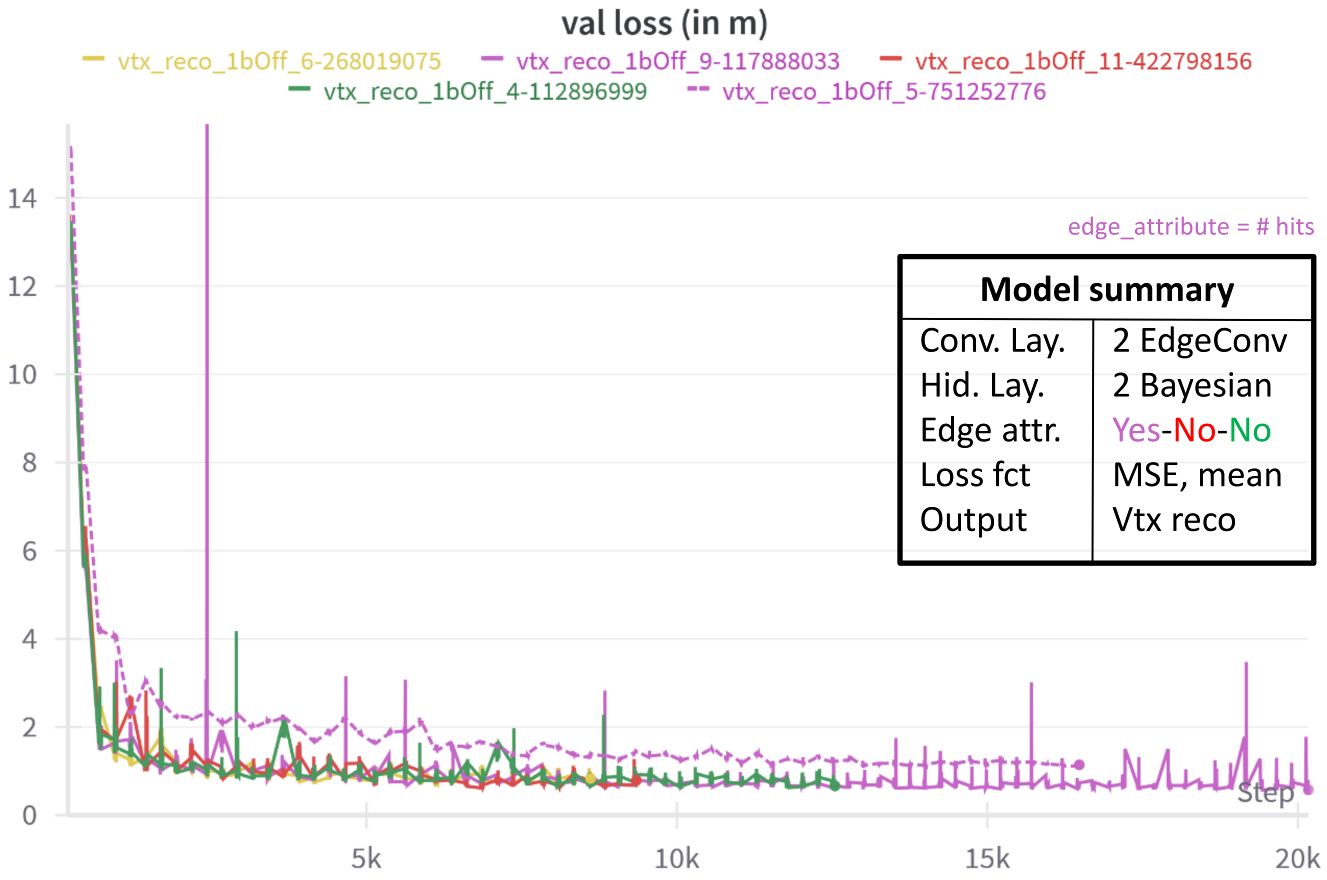
SKYNET-VTX

- General test on 10 MeV positrons in HK without dark noise
- LEAF performance: resolution (68% CL) ≈ 45 cm and ~ 70 cm with dark noise
- First test: GNN regression for {x,y,z}
    - Resolution ≈ 1 m



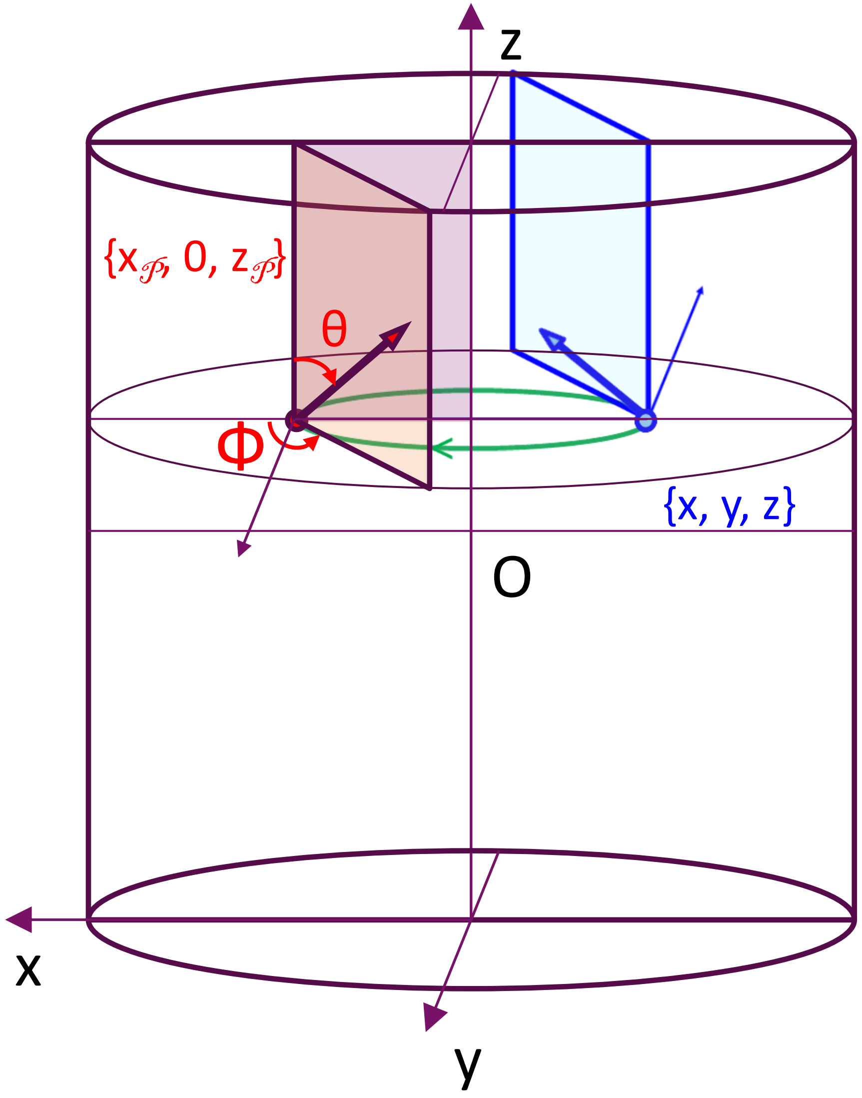
Model summary	
Conv. Lay.	2 EdgeConv
Hid. Lay.	2 Bayesian
Edge attr.	Yes-No-No
Loss fct	MSE, mean
Output	Vtx reco

⇒ Not competitive even though the GNN is not optimized

SKYNET-VTX: SLICE EDITION

- Due to tank symmetry by revolution, all events can be mapped to the slice plane $\mathscr{P}$**:= {y=0, x & z>0}**
    - Rotation around (Oz) the vertex & PMT hits by ϑ_{true}
    - Rotation around (Oz) by ϑ_{true} + flip the vertex & PMT hits
- Second test: **GNN regression for {$x_{\mathscr{P}}$, $z_{\mathscr{P}}$} in $\mathscr{P}$**
    - Resolution ≈ 50 cm

⇒ 3D → 2D regression: interesting results even though the GNN is not optimized

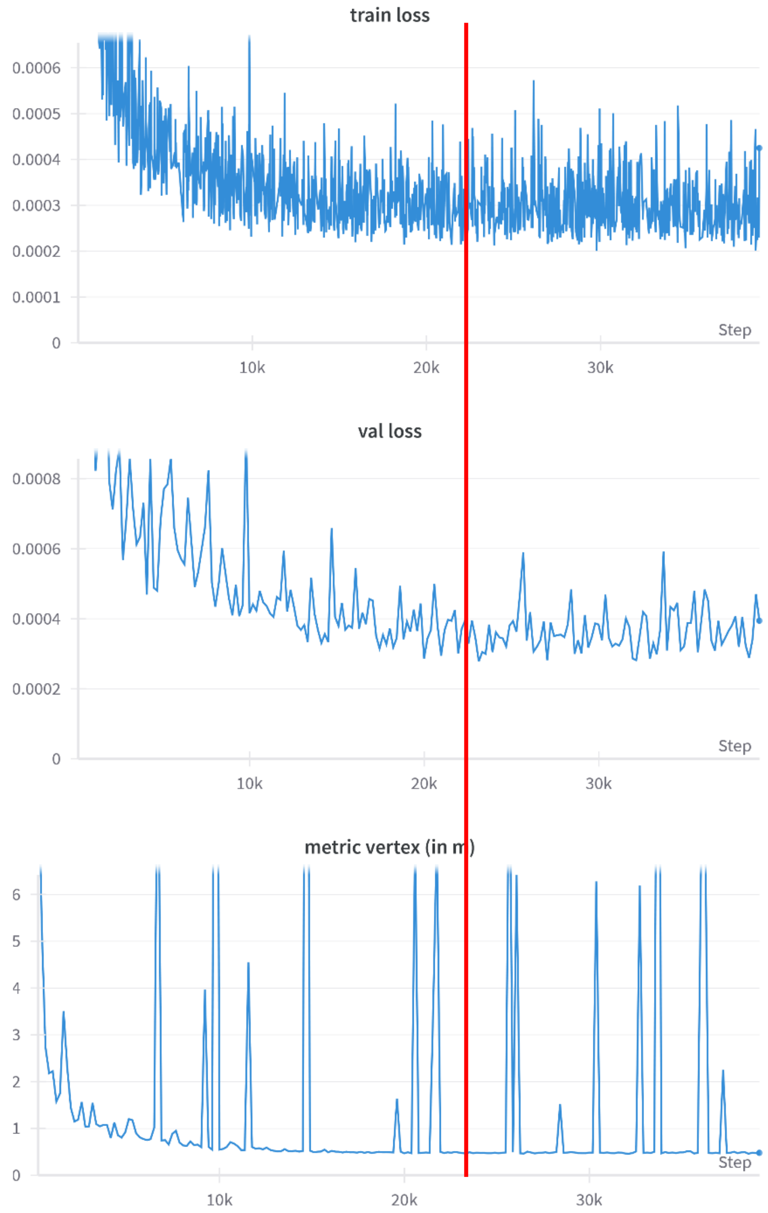


SKYNET-VTX: SLICE EDITION

- Map all events to $\mathscr{P}$ then regression of mapped vertex
- Labels: map vertex in $\mathscr{P}$ $\{x_{\mathscr{P}}, z_{\mathscr{P}}\}$
- Node features: PMT hits $\{X_{\mathscr{P}}, Y_{\mathscr{P}}, Z_{\mathscr{P}}, T\}$
- Convolution layers: DynamicEdgeConv
- Hidden and final layers: Bayesian
- Output: vertex $\{x_{\mathscr{P}}', z_{\mathscr{P}}'\}$
- Loss function: RMSE

Model summary	
Conv. Lay.	5 EdgeConv
Hid. Lay.	5 Bayesian
Edge attr.	# of hits
Loss fct	RMSE
Output	Vtx reco
Epoch	**118**
Reso. 68%	**47.6 cm**

10 MeV positrons in HK without dark noise



⇒ Best resolution @ 47.6 cm for RMSE

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10 MeV positrons in HK without dark noise

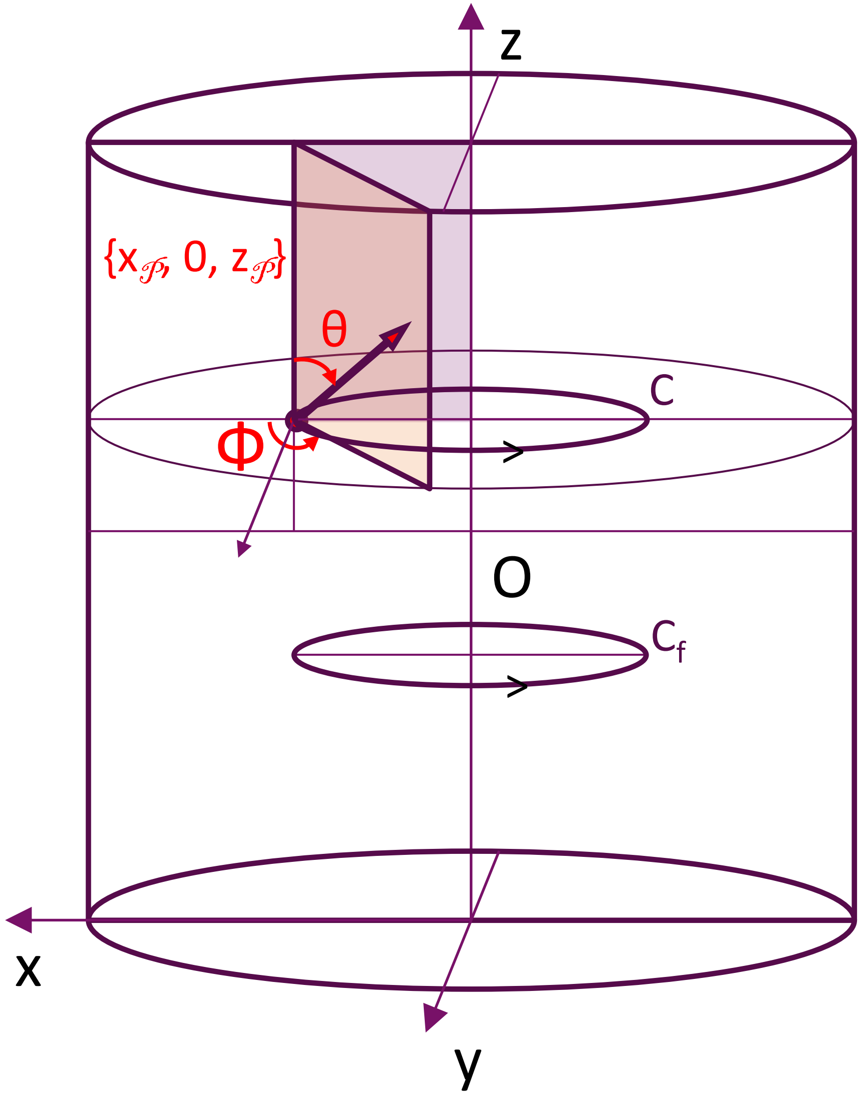
What are these peaks ?
Is this normal or do I have a bug ?

⇒ Best resolution @ 47.6 cm for RMSE

(… or do I have a bug ?)

SLICE EDITION, MAIN ISSUES

- Reconstruct $\{x_{\mathscr{P}}, z_{\mathscr{P}}, \mathbf{t}\}$ and not $\{x, y, z, \mathbf{t}\}$
    - Additional step to find the best vertex over two circular pathes C and C_f



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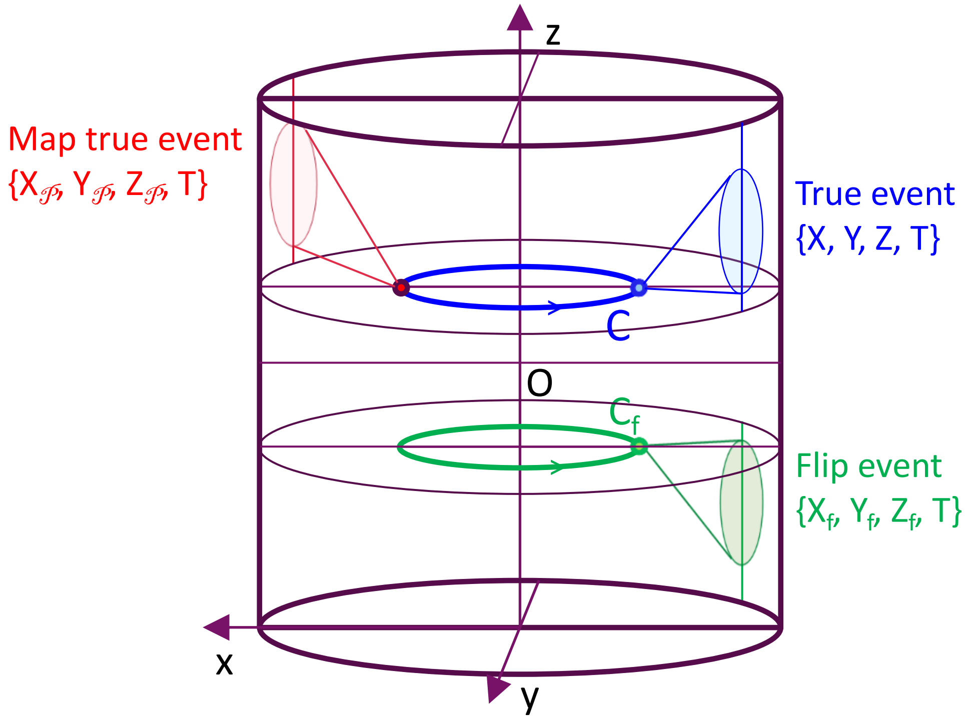
- Real event PMT info $\{X, Y, Z, T\}$ and not $\{X_{\mathscr{P}}, Y_{\mathscr{P}}, Z_{\mathscr{P}}, T\}$
  - Not possible to directly map PMTs to $\mathscr{P}$
  - C: path generated by $\{X, Y, Z, T\}$ rotated from 0 to 2π
  - C_f: path generated by $\{X, Y, Z, T\}$ flipped around (Ox) then rotated from 0 to $2\pi \rightarrow \{X_f, Y_f, Z_f, T\}$



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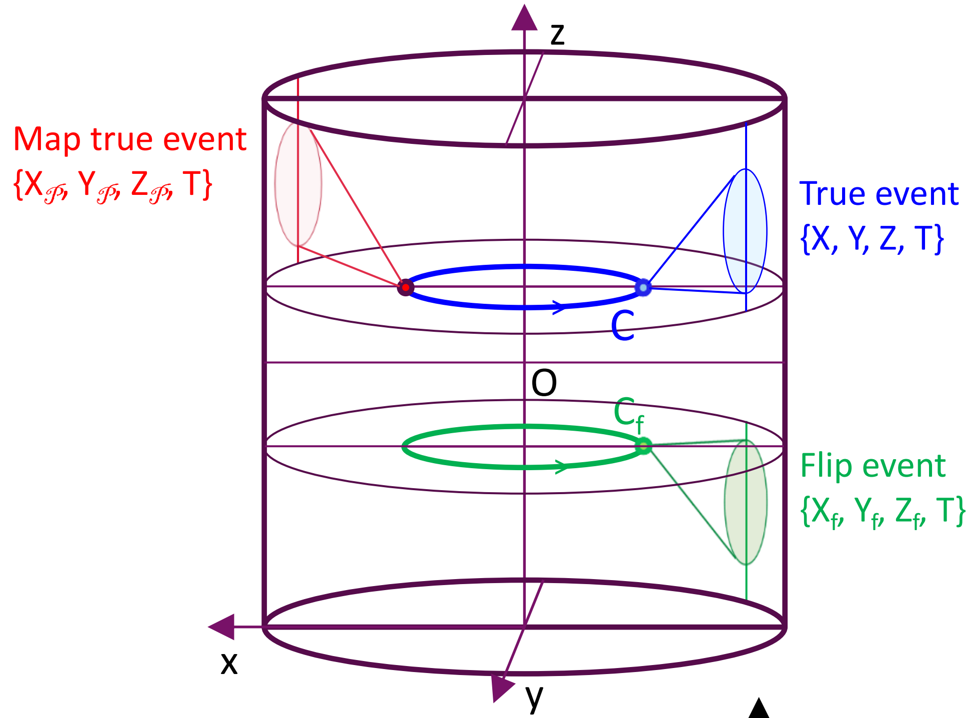
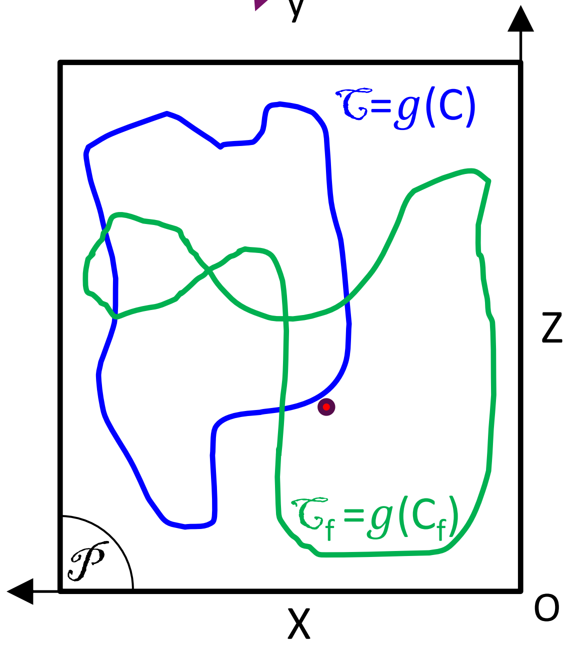
- Define a function g over C and C_f: $g(\{X, Y, Z, T\}_\theta) \mapsto \{x_{\mathscr{P}}, z_{\mathscr{P}}, t\}_\theta$
  - $\mathscr{C}=g(C)$ and $\mathscr{C}_f=g(C_f)$ in $\mathscr{P}$ are continuous (trivial proof if GNN function is continuous, proof by computation on a grid otherwise)
  - Best candidate vertex = minimize a continuous a continuous function f defined in $\mathscr{P}$ i.e. over $\mathscr{C}$ and $\mathscr{C}_f$

$$f(\theta) \coloneqq \text{NLL} = \sum_{PMT(\theta)} -\log\big(P(t_{PMT(\theta)} - t_{VTX} - TOF)\big)$$

  - In the slice $\mathscr{P}$, **best candidate vertex ~ map true event**





CONTINOUS FUNCTIONS g, f IN $\mathscr{P}$

- Define a function g over C and C_f:

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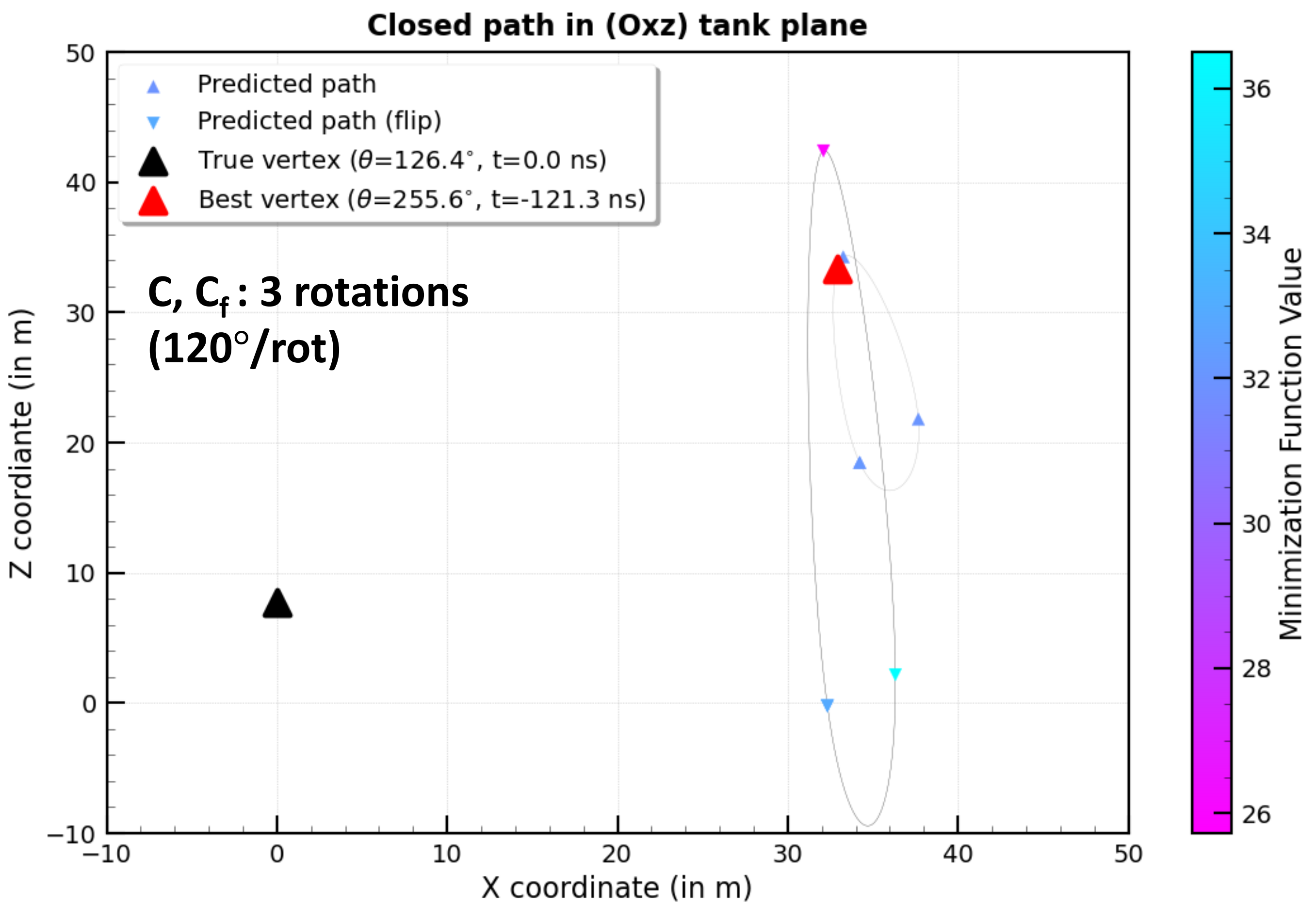
- **$\mathfrak{C}=g(C)$ and $\mathfrak{C}_f=g(C_f)$ in $\mathscr{P}$ are continuous: proof by computation on a grid**

- Best candidate vertex = minimize a continuous function f defined in $\mathscr{P}$ i.e. over $\mathfrak{C}$ and $\mathfrak{C}_f$

$$f(\theta) = \sum_{PMT(\theta)} -\log\big(P(t_{PMT(\theta)} - t_{VTX} - TOF)\big)$$

- TO PROVE: In the slice $\mathscr{P}$, best candidate vertex ~ map true event



Note: slight variation of points due to Bayesian layers ;
use mean GNN output over 100 iterations for each points, σ(mean)≈10%

Note2: the model used here had a bug, could not patch it in time for the meeting, that's the reason why best vertex ≠ map true event

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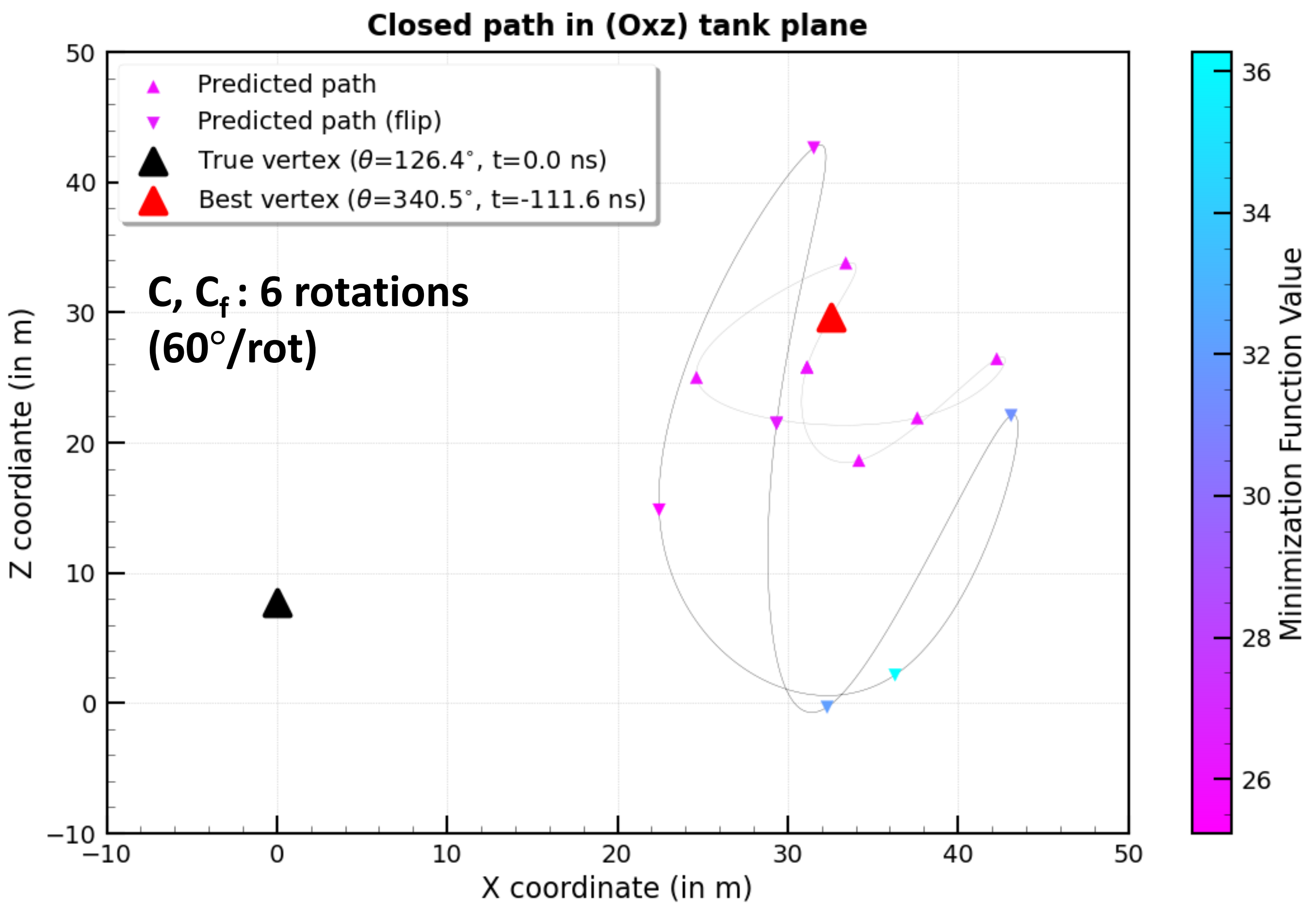

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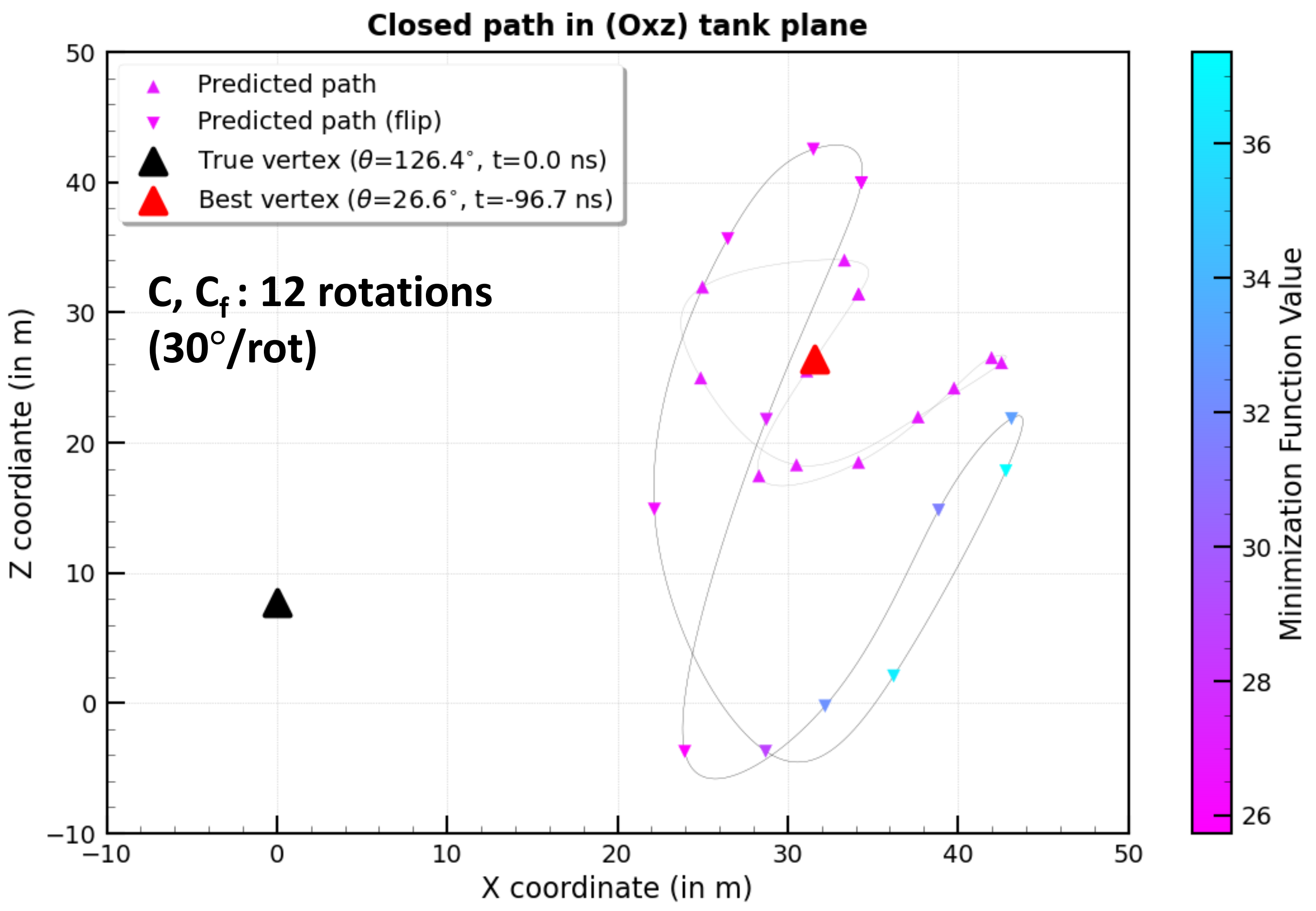

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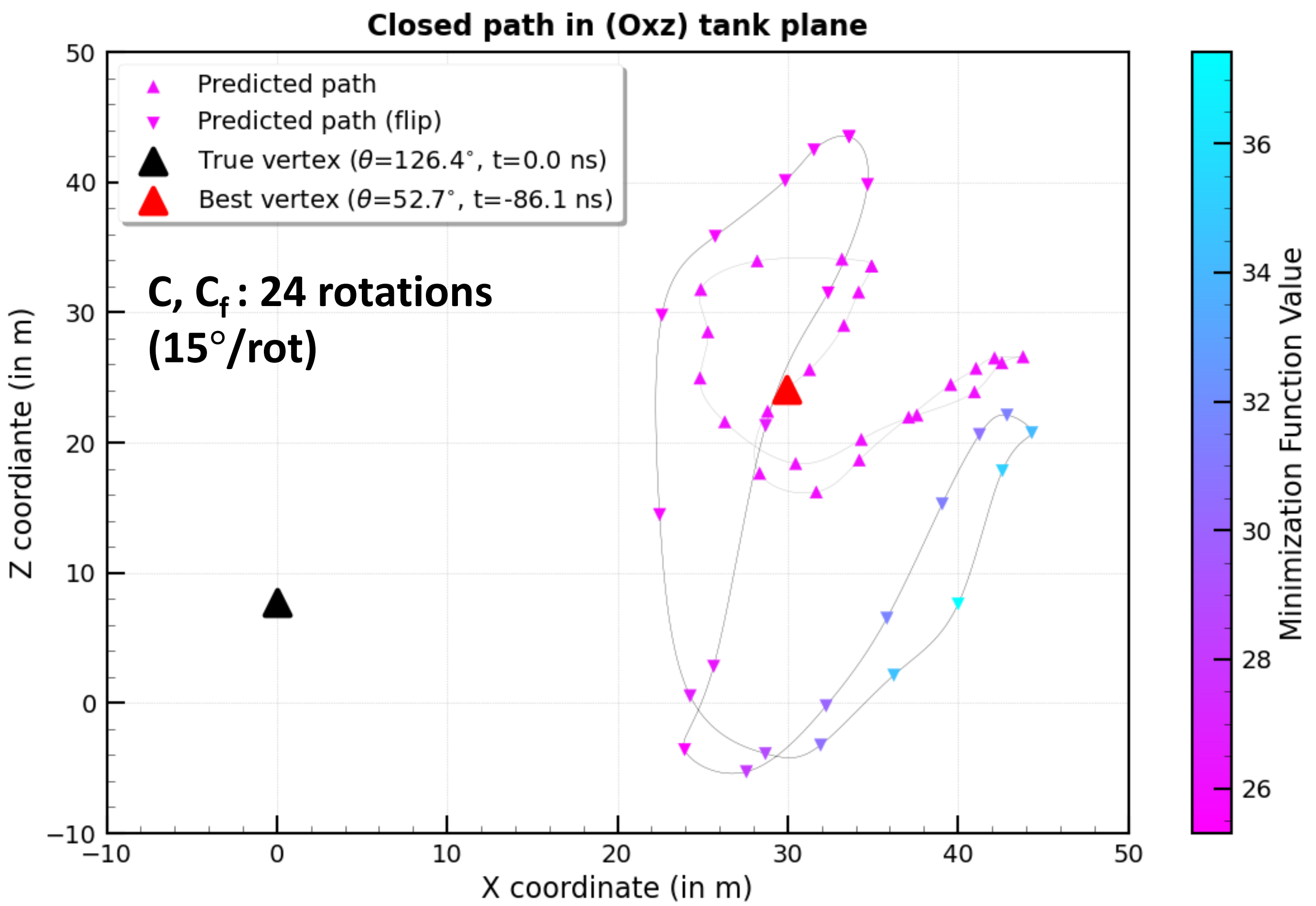

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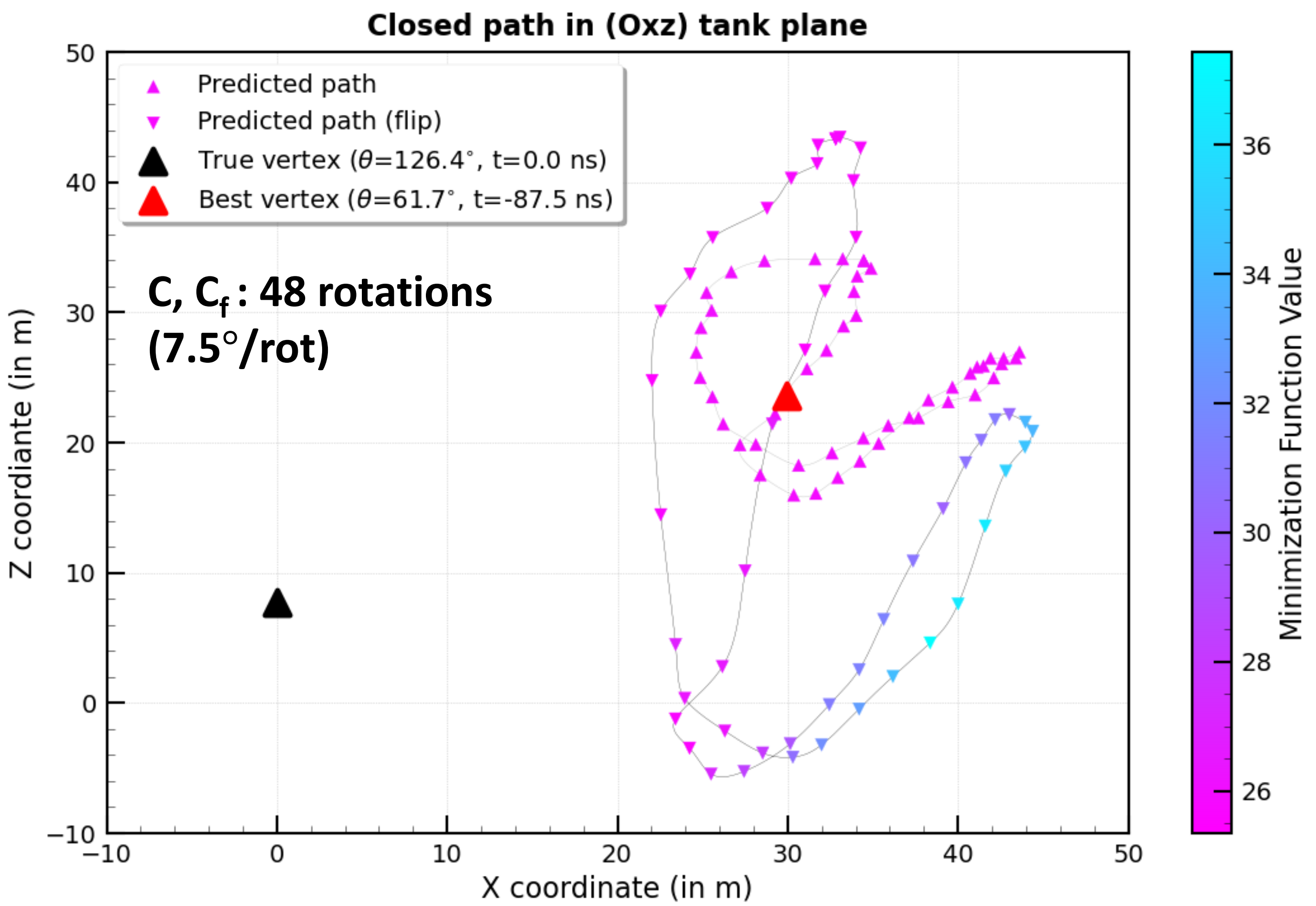

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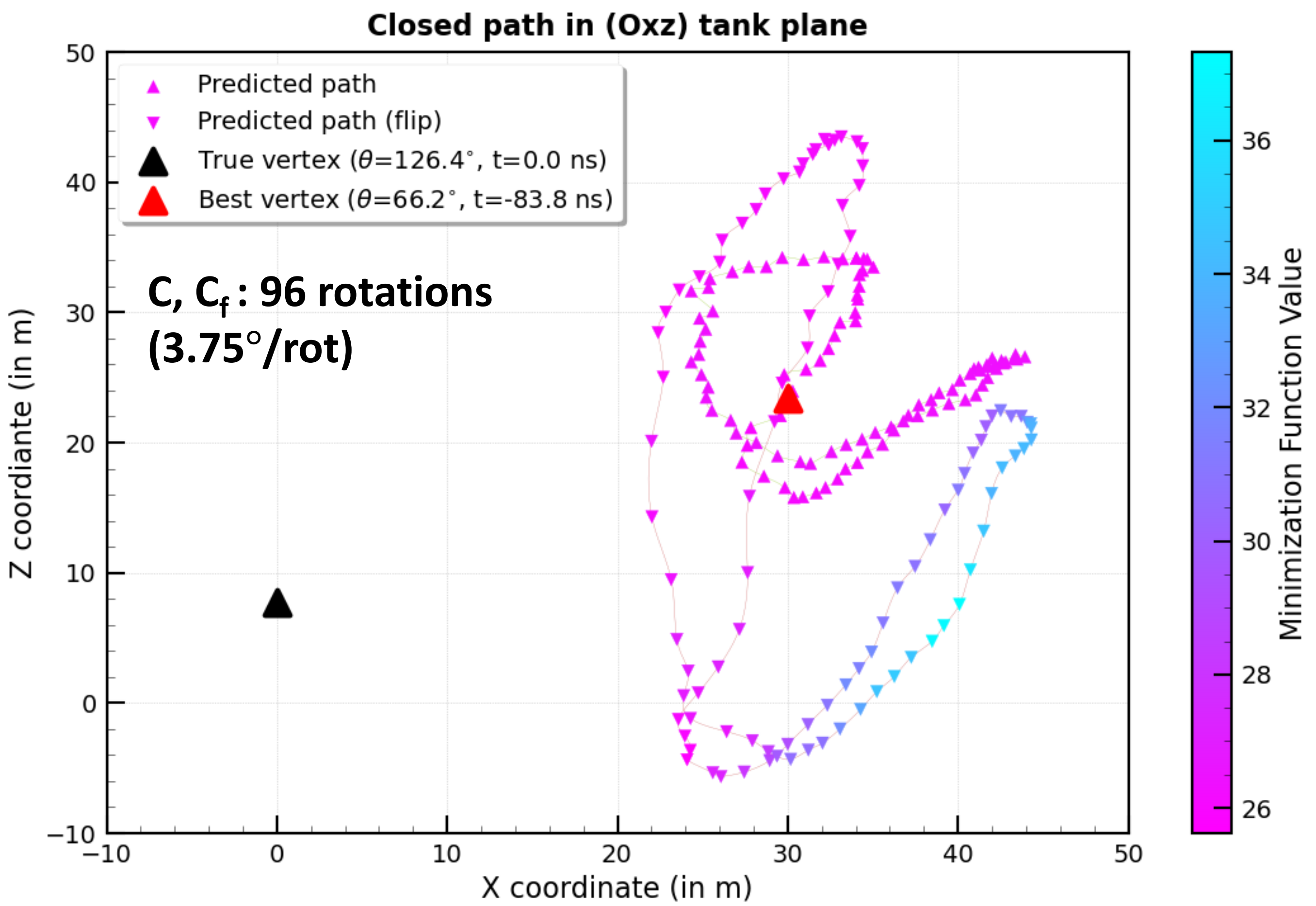

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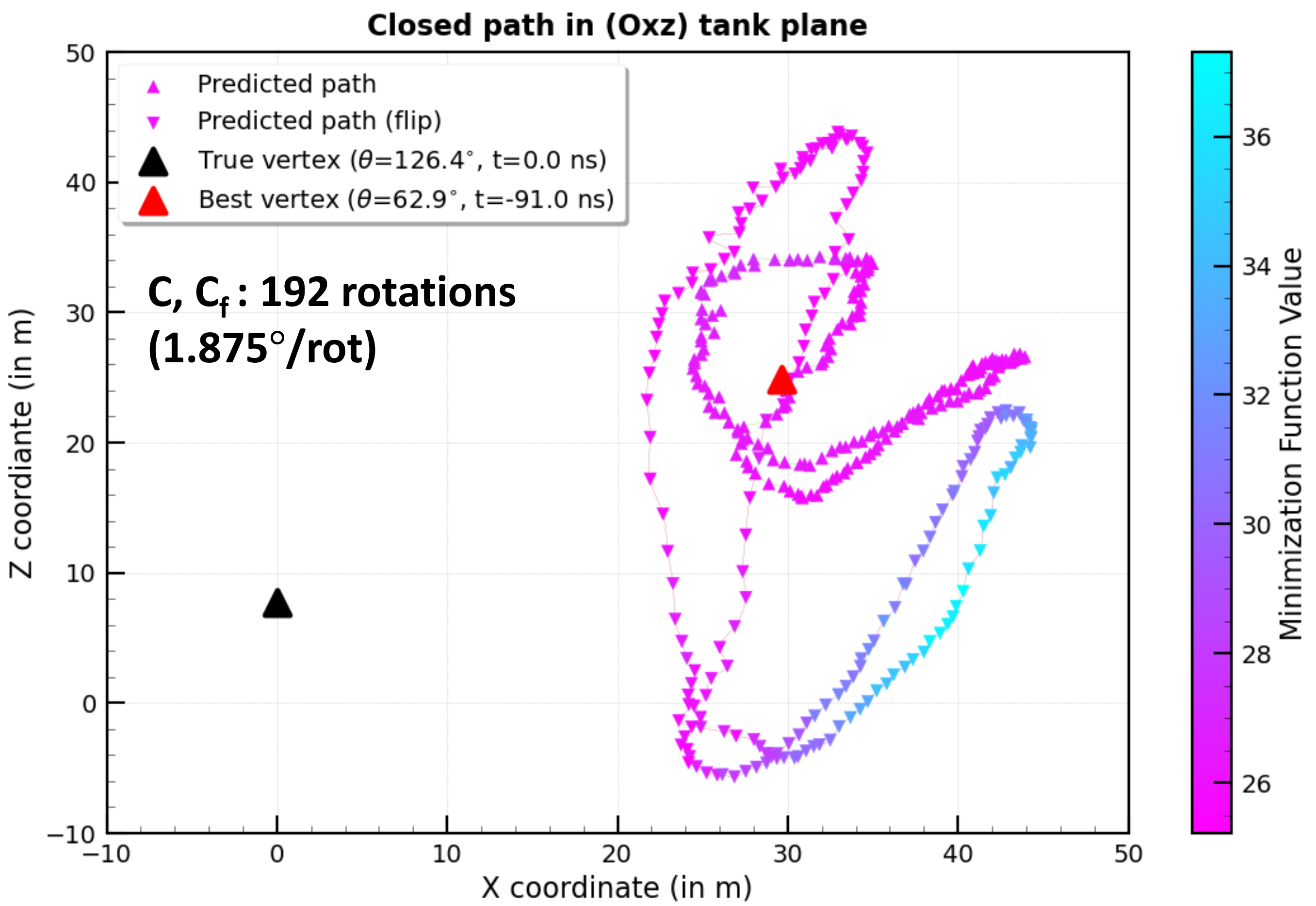

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CONCLUSION

3D → 2D vertex regression :

- Continuous behavior of mapping functions g and f checked
- Algorithm ready for 2D vertex regression + f–minimization in $\mathscr{P}$
- Waiting for CC-IN2P3 to run jobs

Next steps, 3 directions:

- **Optimization of resolution**: hyper parameters, GPU time, # rotation for C and C_f, # of interpol. points in $\mathfrak{C}=g(C)$ and $\mathfrak{C}_f=g(C_f)$, # of Bayesian iterations
  - Maybe to be done by interns in April if resolution + GPU time are satisfactory for first analysis ?
- **Development:** Add direction & energy (most of the algorithm is written, comparison + optimization needs to be done)
- **Analysis:** neutron classification, rework SKYNET-class for WCTE (use mPMT) + benchmark with Antoine version
  - WCTE neutron tagging analysis: mean path in Gd-loaded water (+ is resolution possible ?), tagging accuracy