Hybrid Ray Tracer

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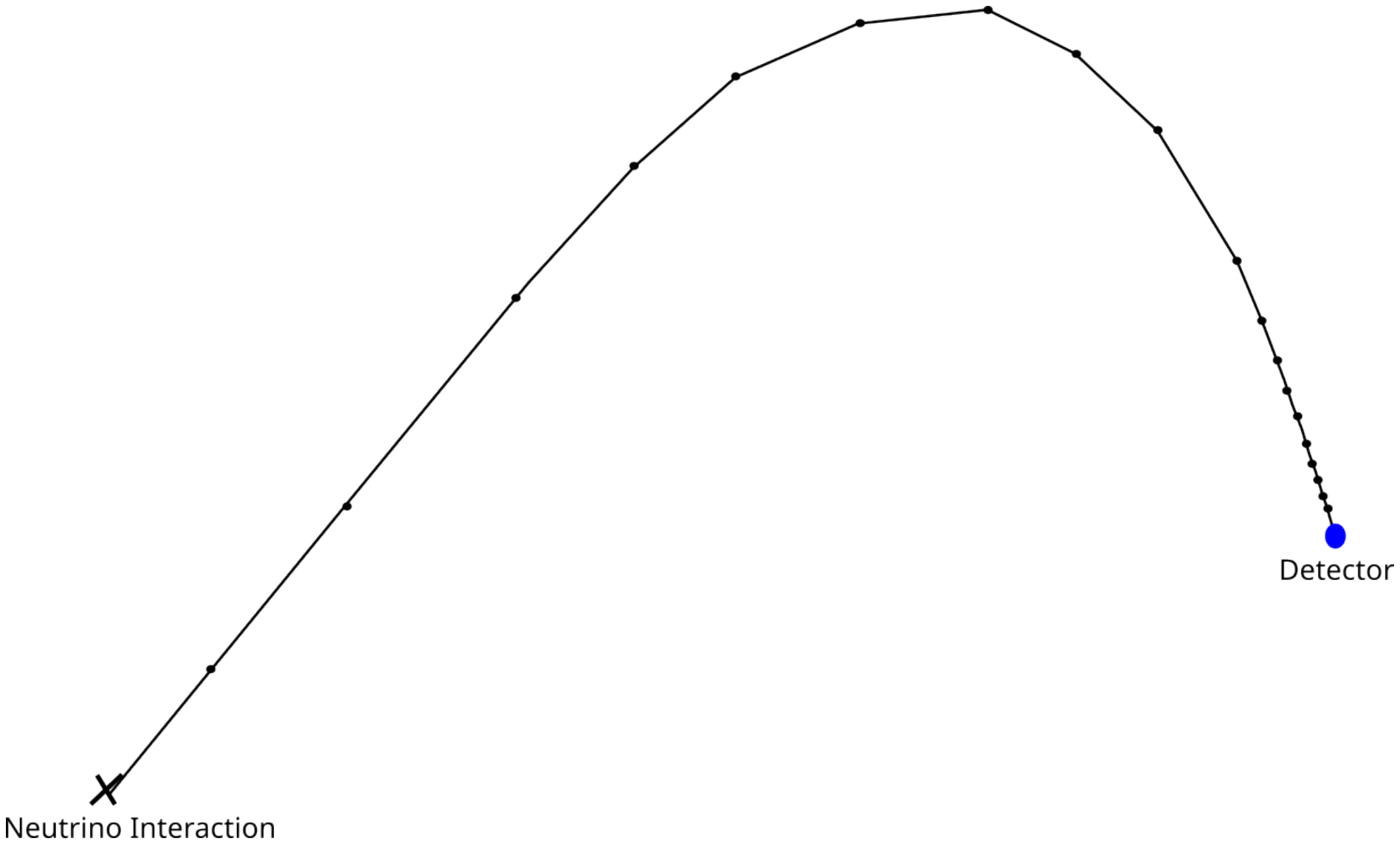
Why?

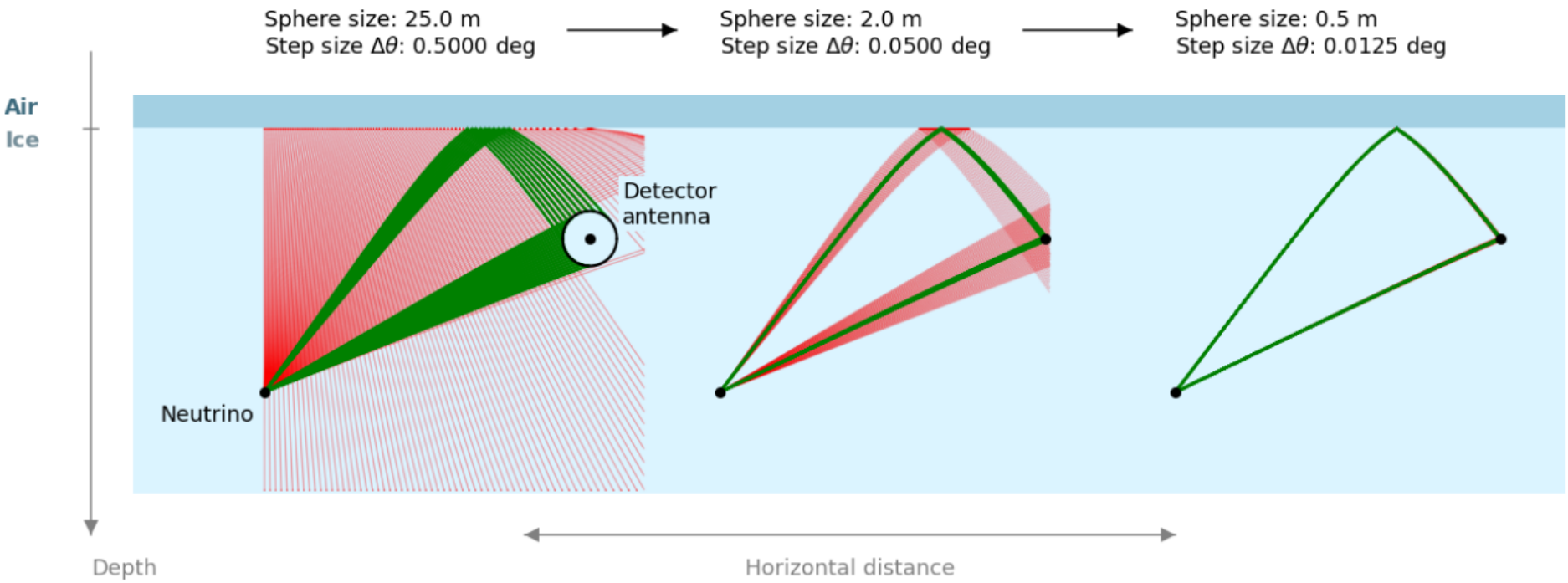
Complex ice models needed

what?



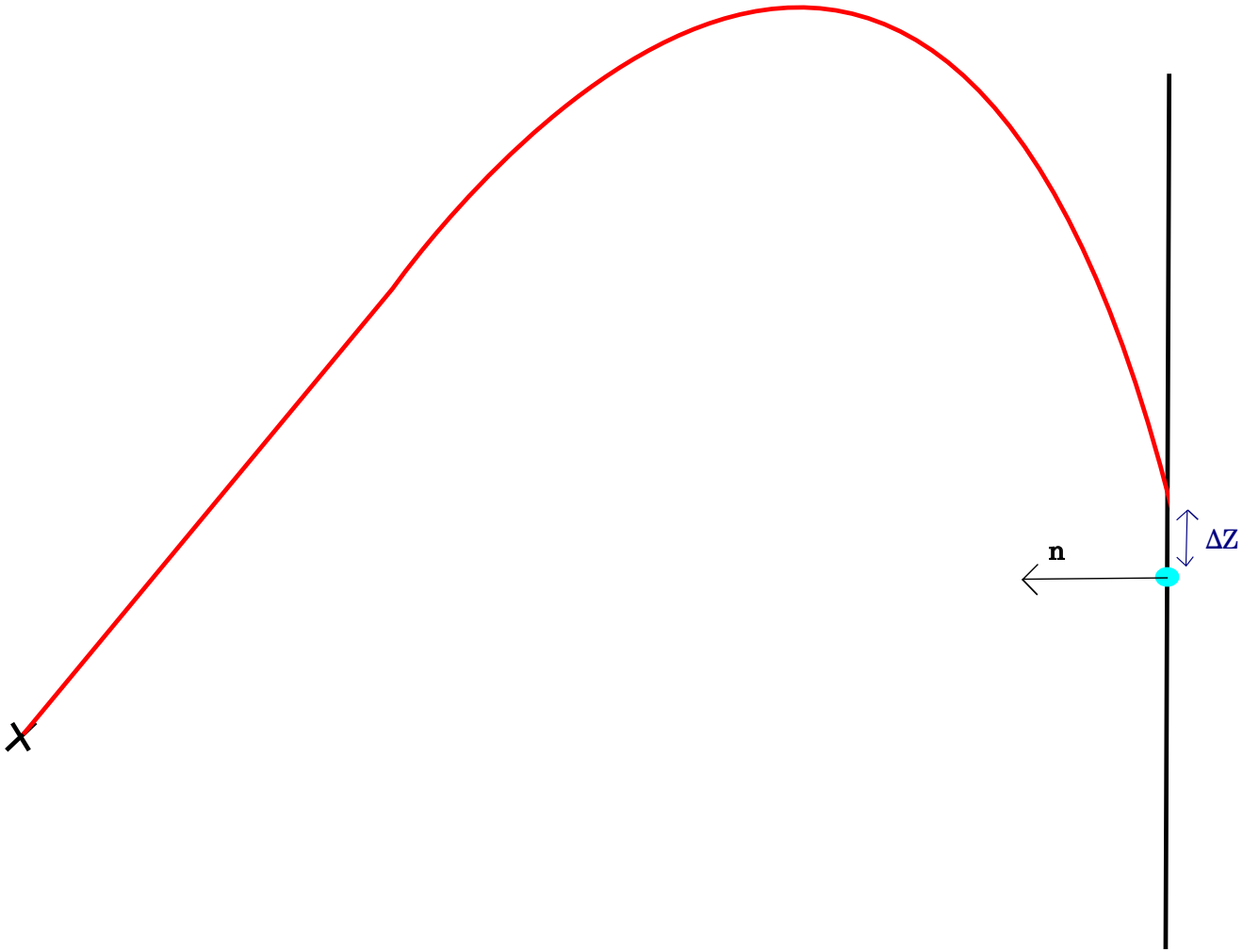
1. How the iterative ray tracer works
2. previous attempt to make it better
3. my attempt to make it better
4. optimisation of my attempt (the hybrid raytracer)
5. final results

Iterative ray tracer

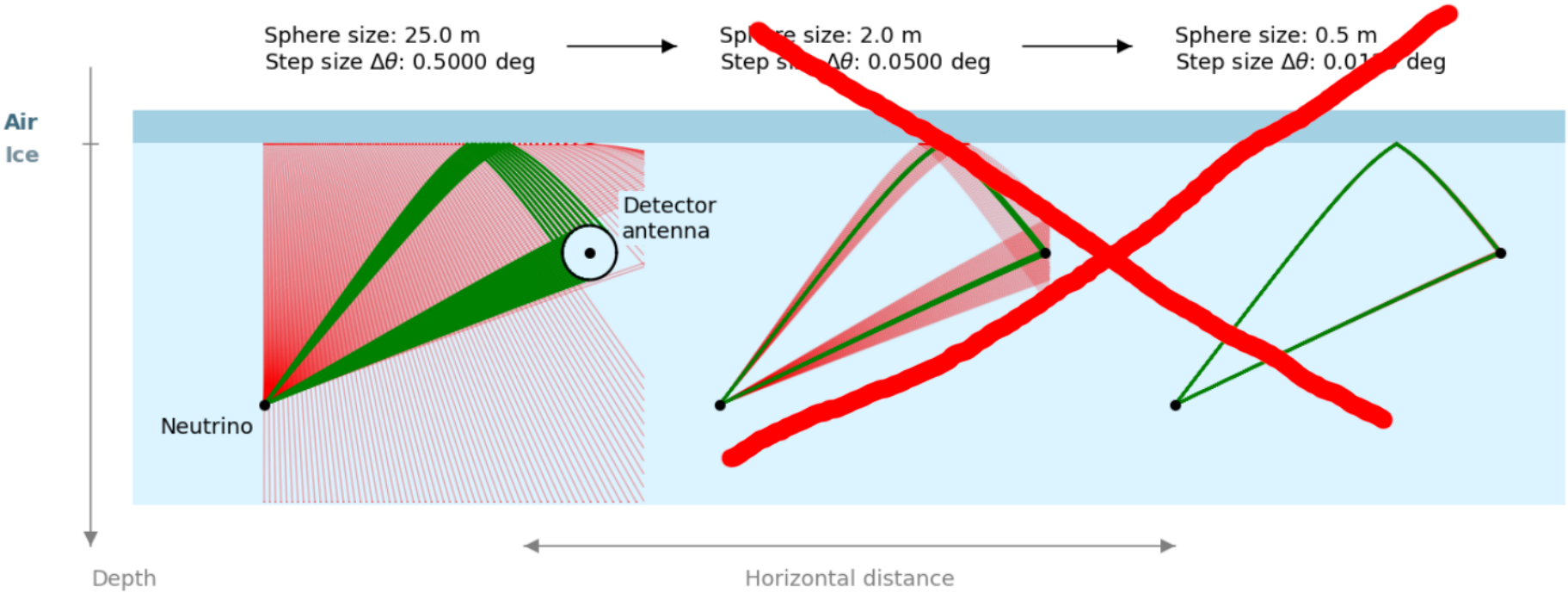


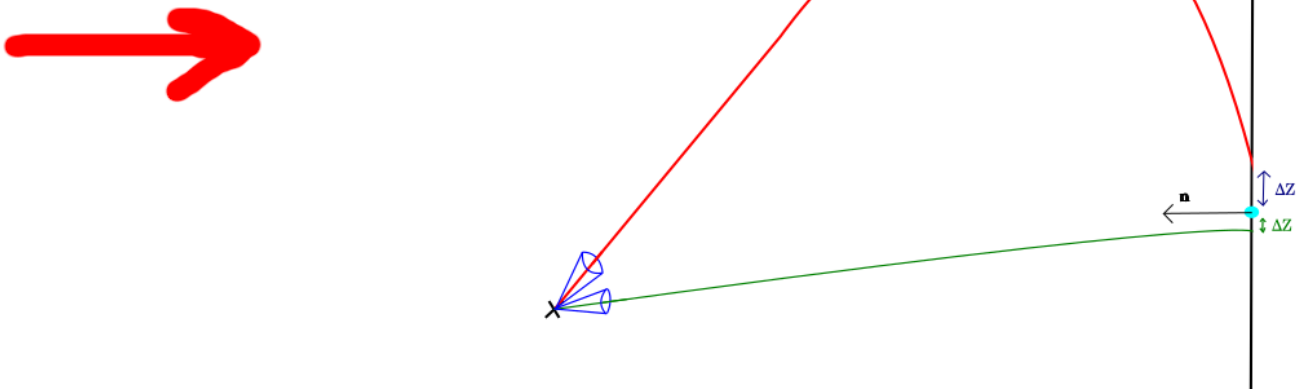
Non optimal $\rightarrow$ scipy.optimize.minimize

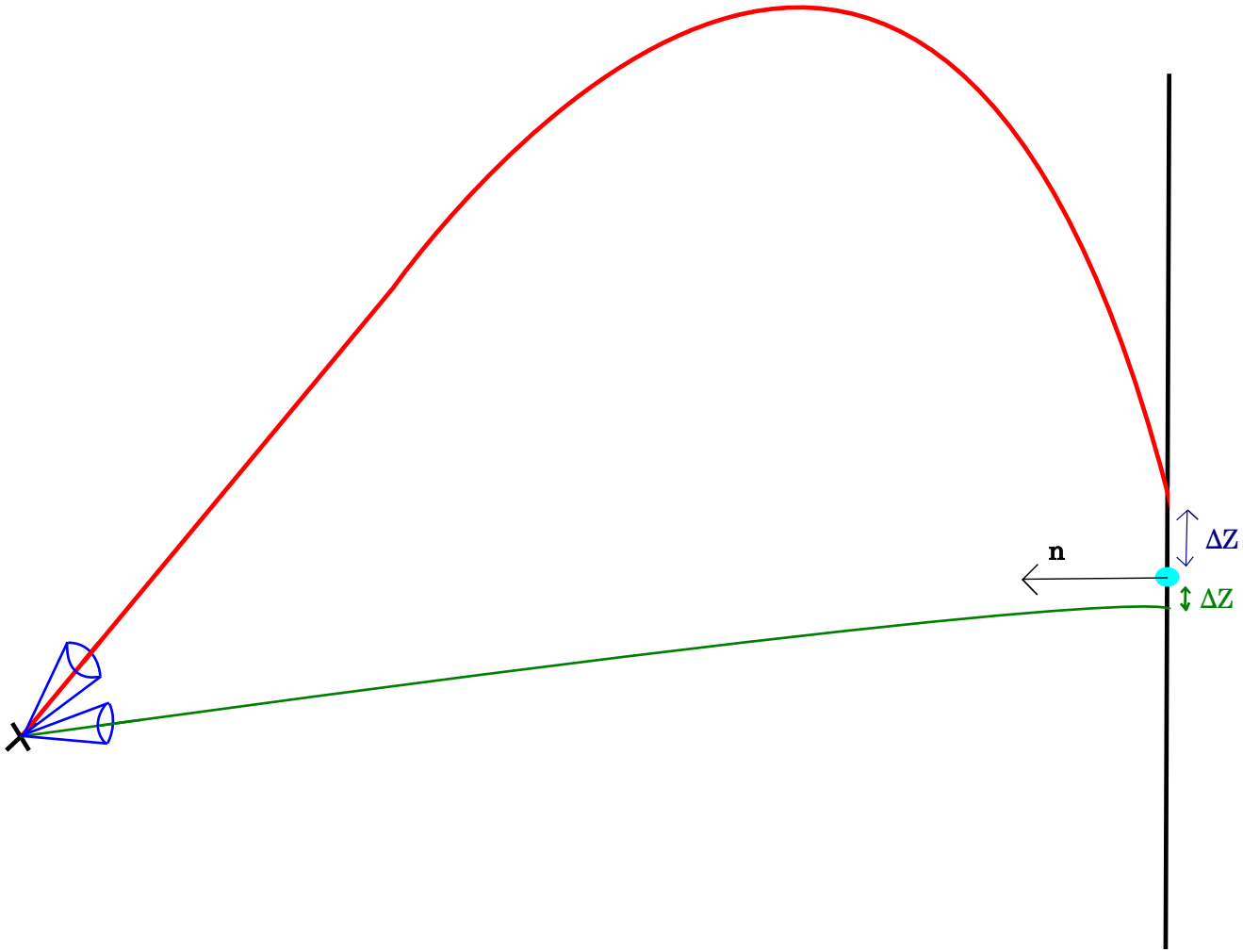
$\Longrightarrow$ minimizer


n
ΔZ

Problem: How to find the intervals?


Sphere size: 25.0 m
Step size Δθ: 0.5000 deg
Sphere size: 2.0 m
Step size Δθ: 0.0500 deg
Sphere size: 0.5 m
Step size Δθ: 0.01 deg
Air
Ice
Detector
antenna
Neutrino
Depth
Horizontal distance


n
ΔZ
ΔZ


n
ΔZ
ΔZ

hybrid - analytic

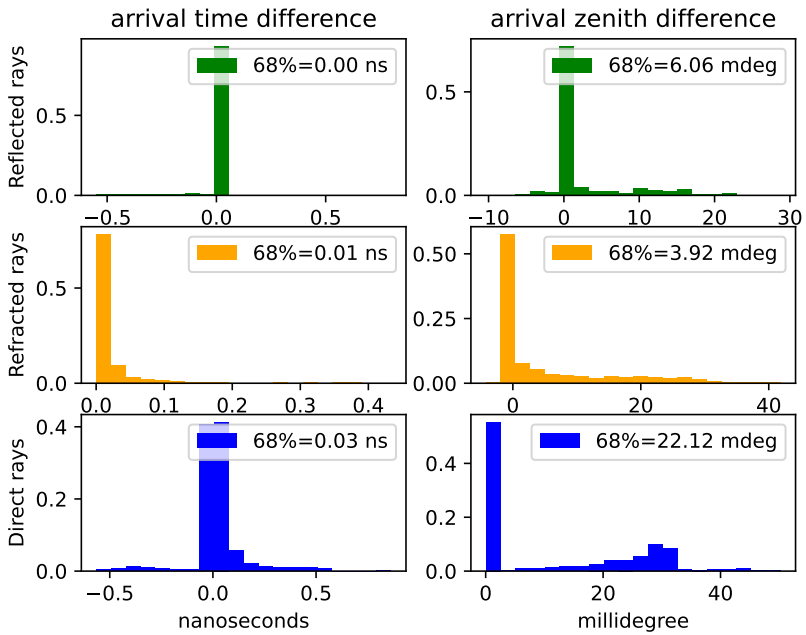


Figure: Hybrid

iterative - analytic

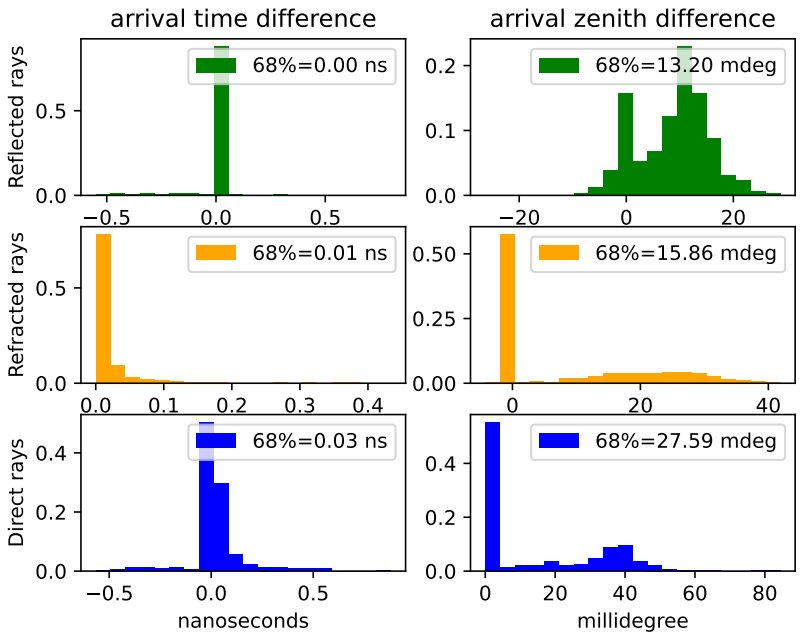
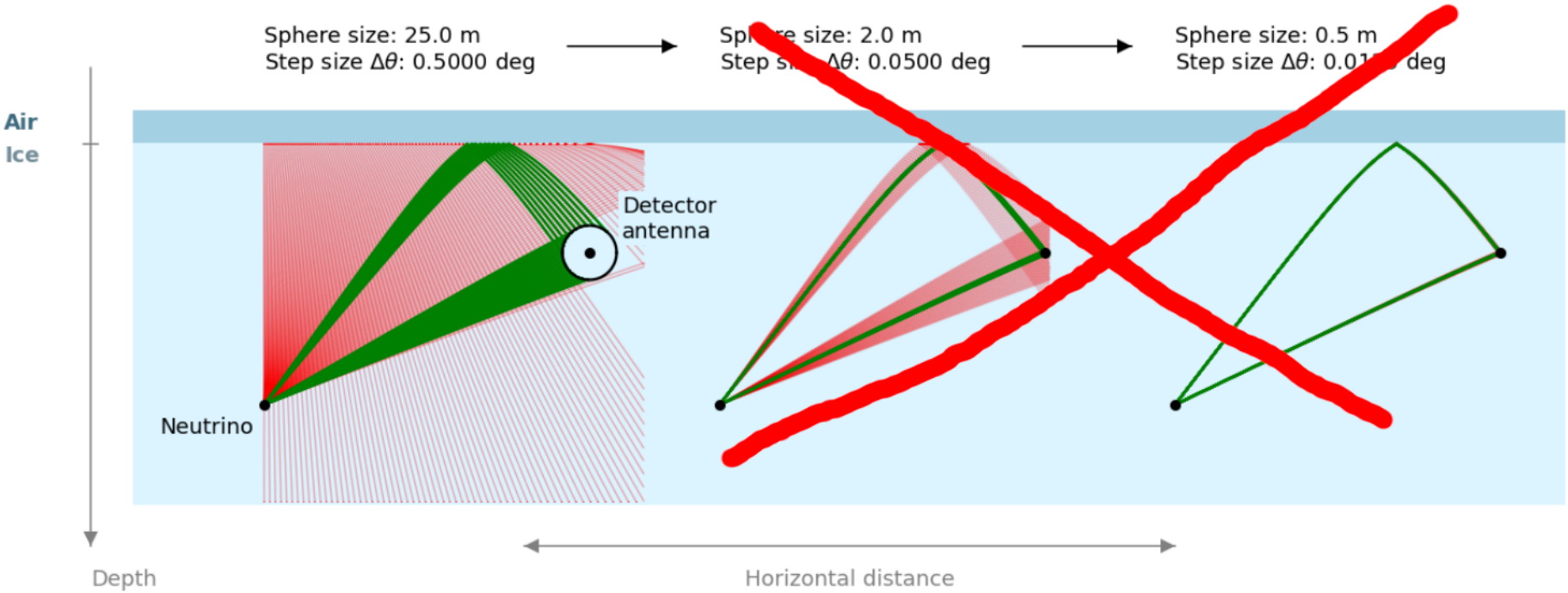
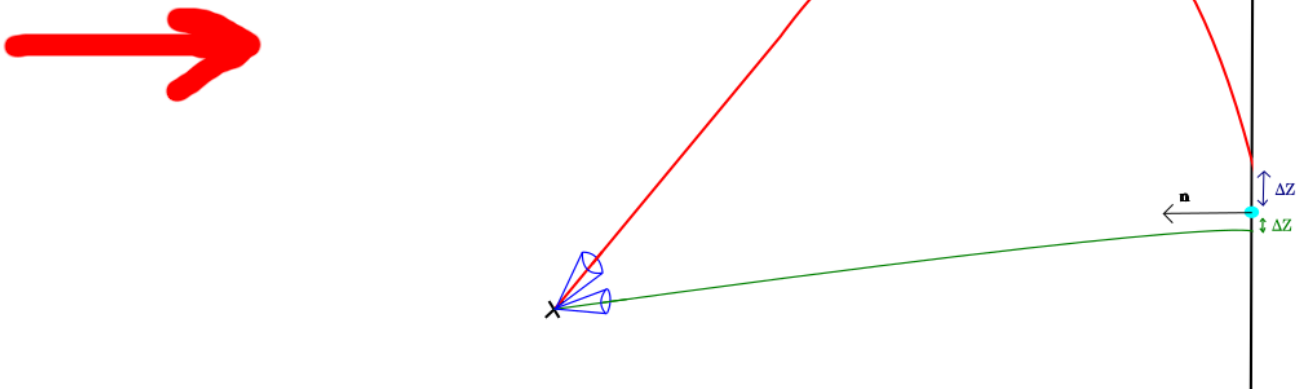


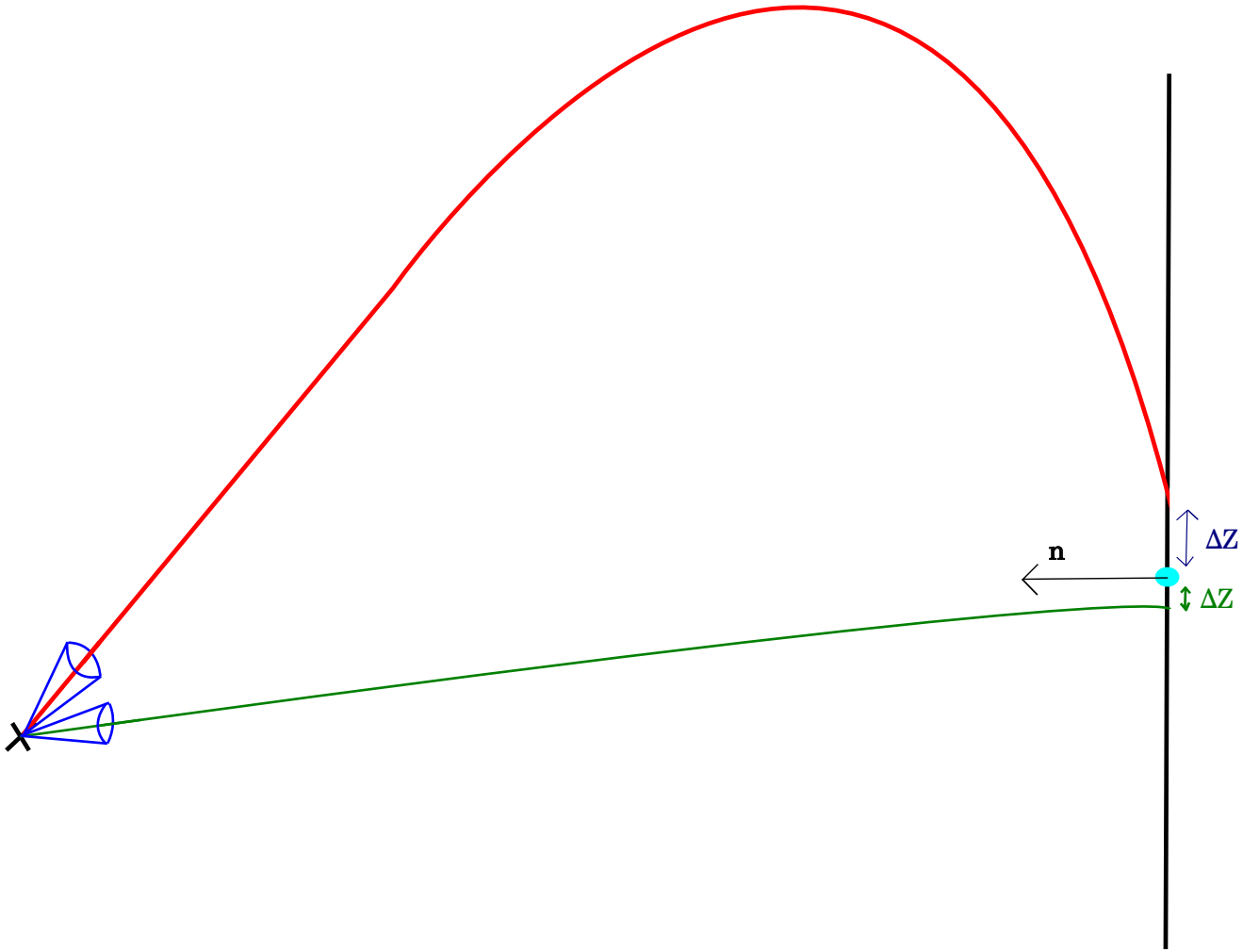
Figure: Iterative

Whilst $\approx$ 15% faster

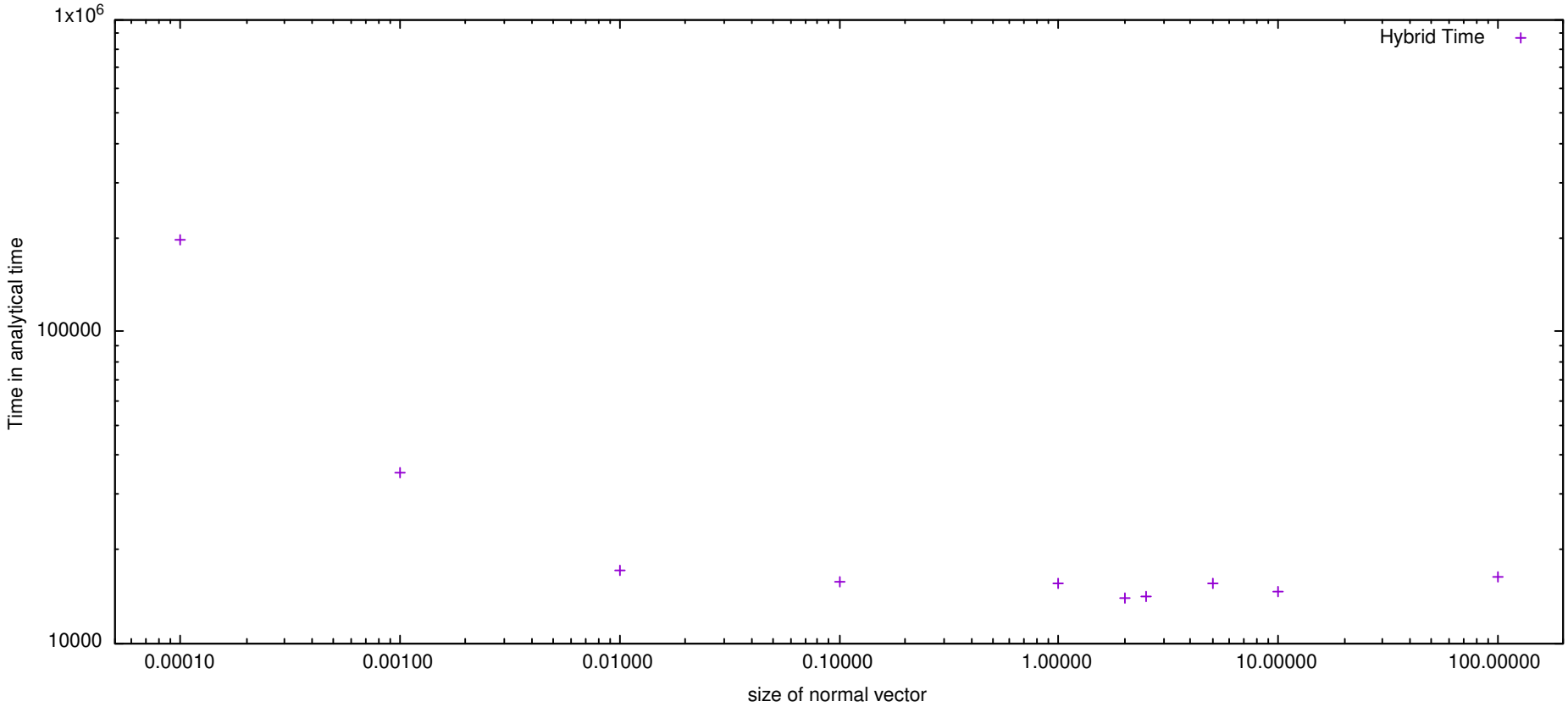
Optimization

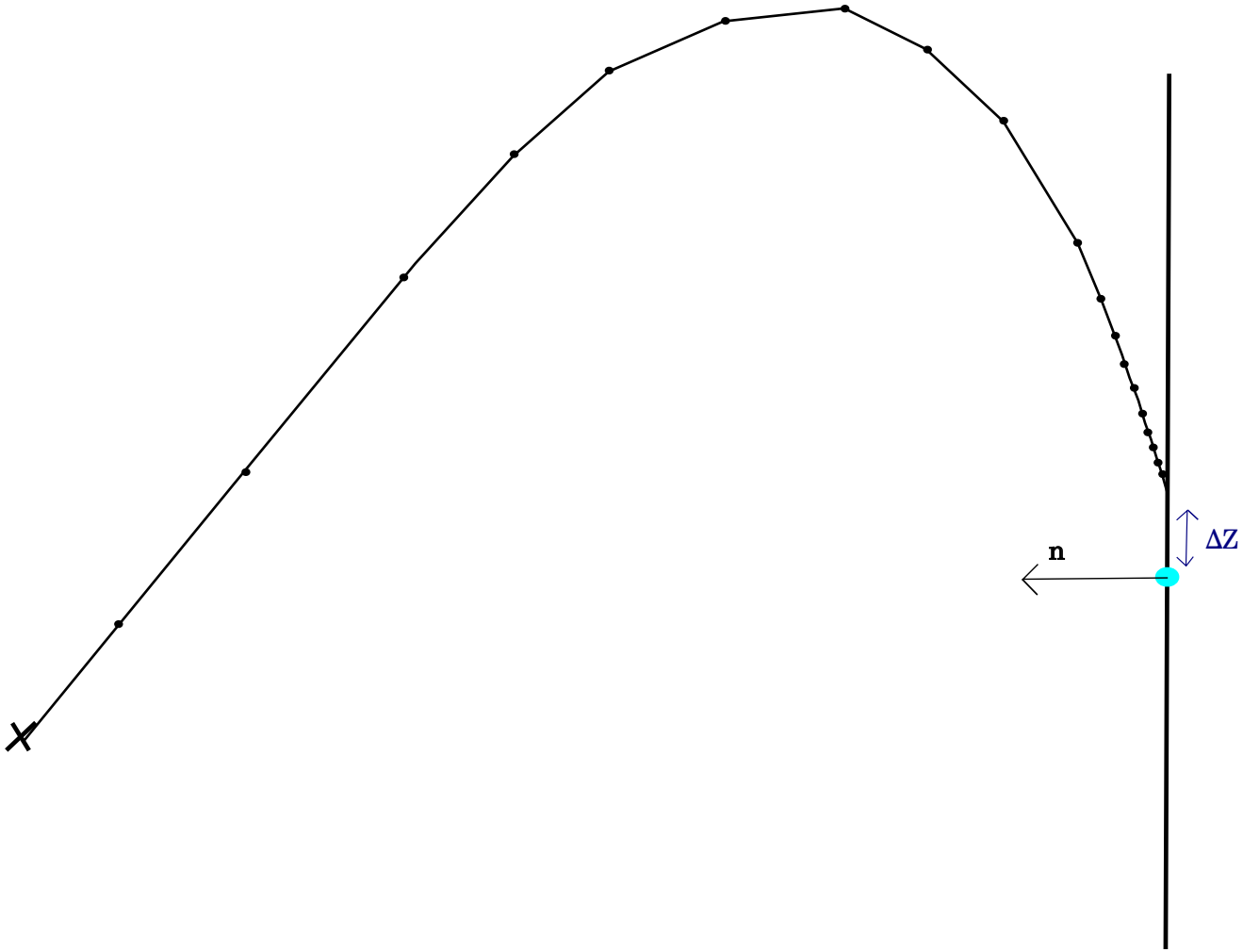

Sphere size: 25.0 m
Step size Δθ: 0.5000 deg
Sphere size: 2.0 m
Step size Δθ: 0.0500 deg
Sphere size: 0.5 m
Step size Δθ: 0.01 deg
Air
Ice
Detector
antenna
Neutrino
Depth
Horizontal distance

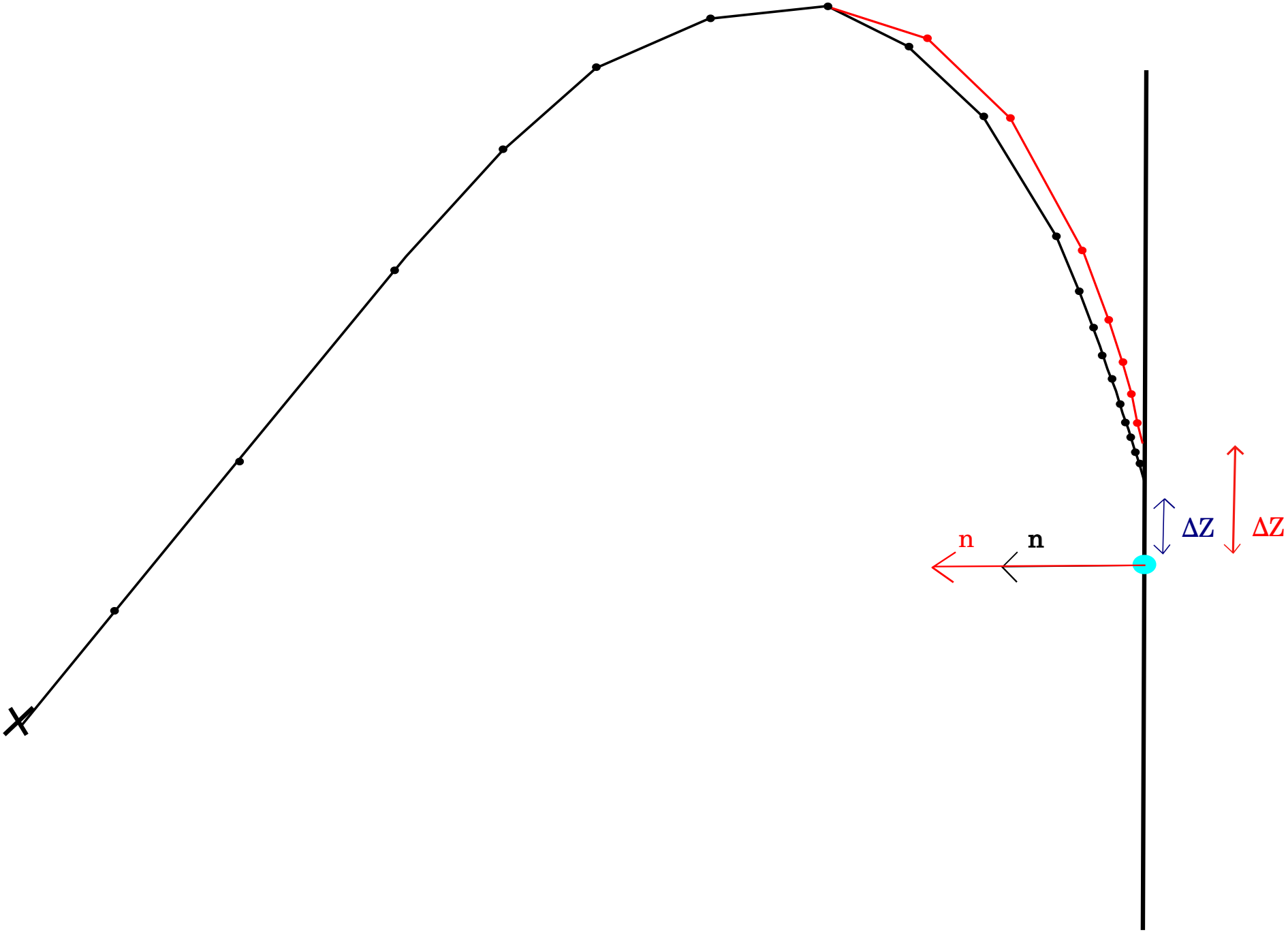

n
ΔZ
ΔZ

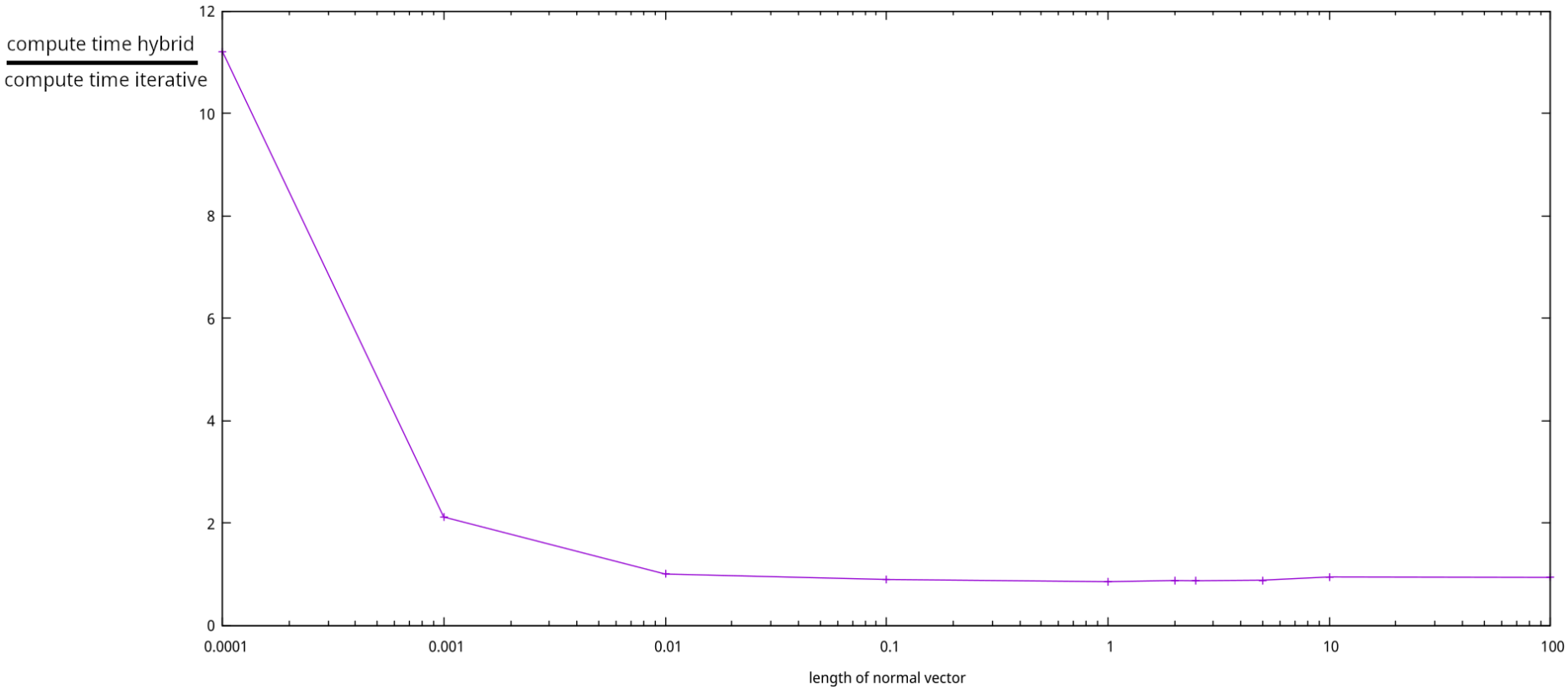

n
ΔZ
ΔZ

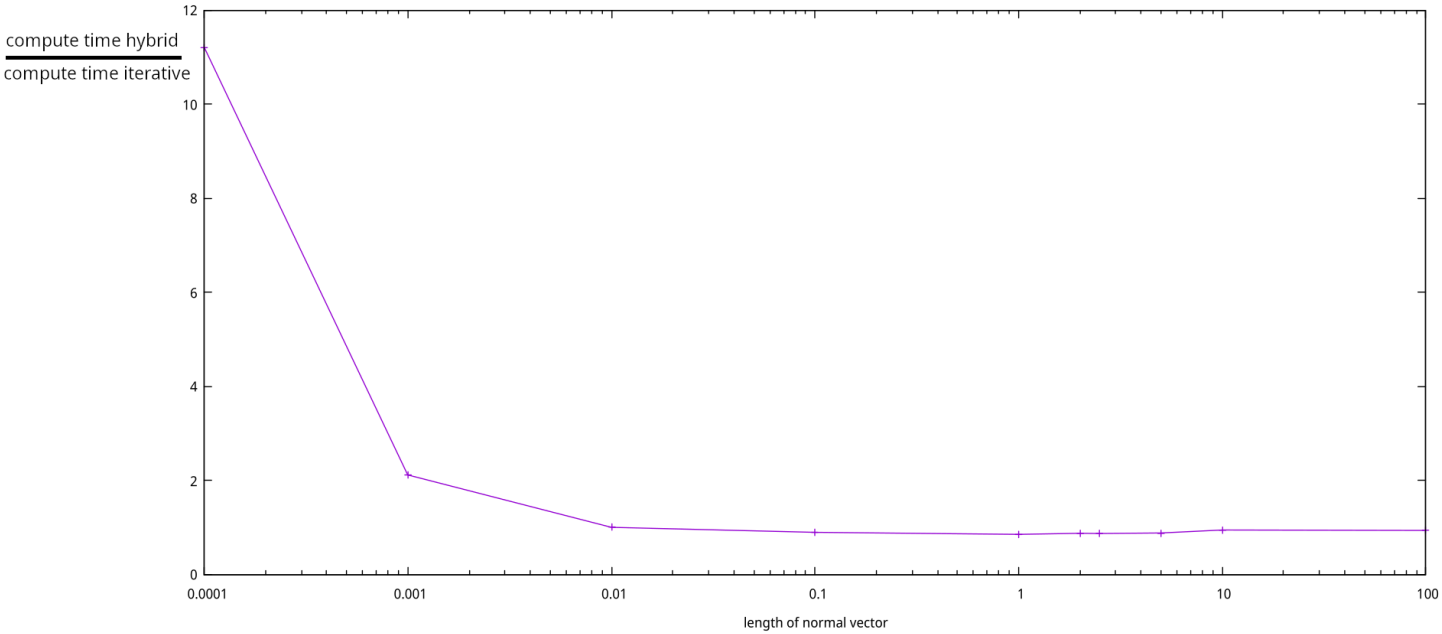
Length of the normal vector:

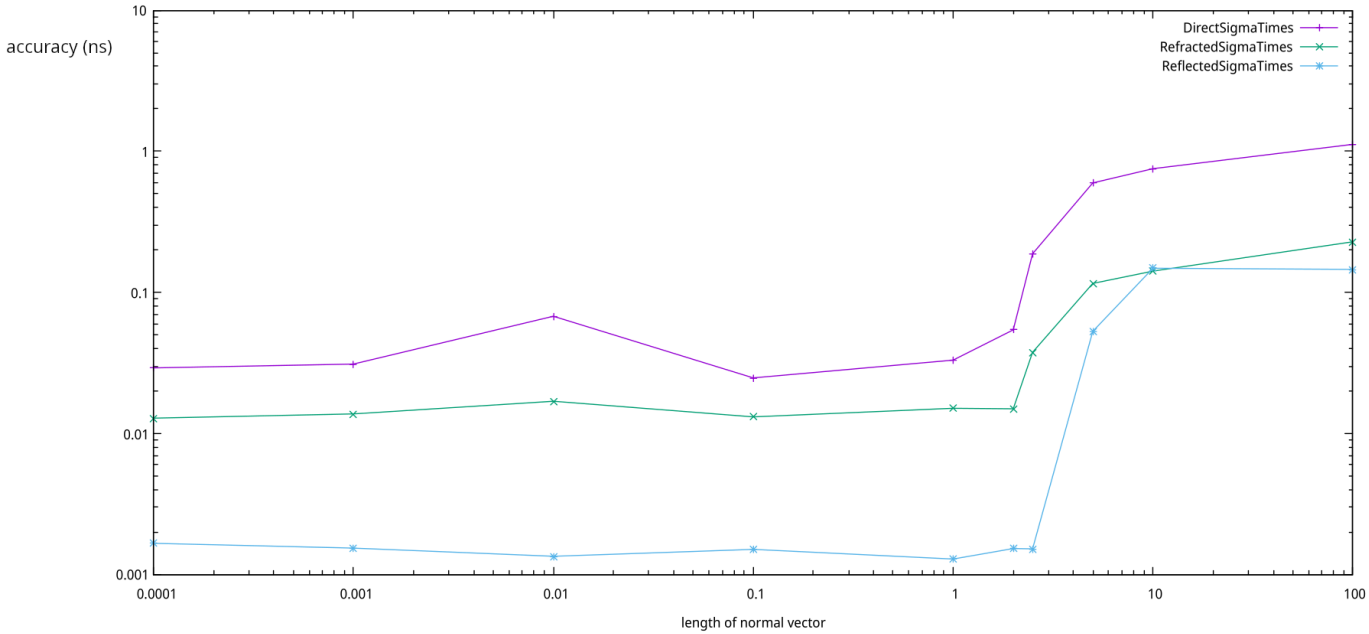


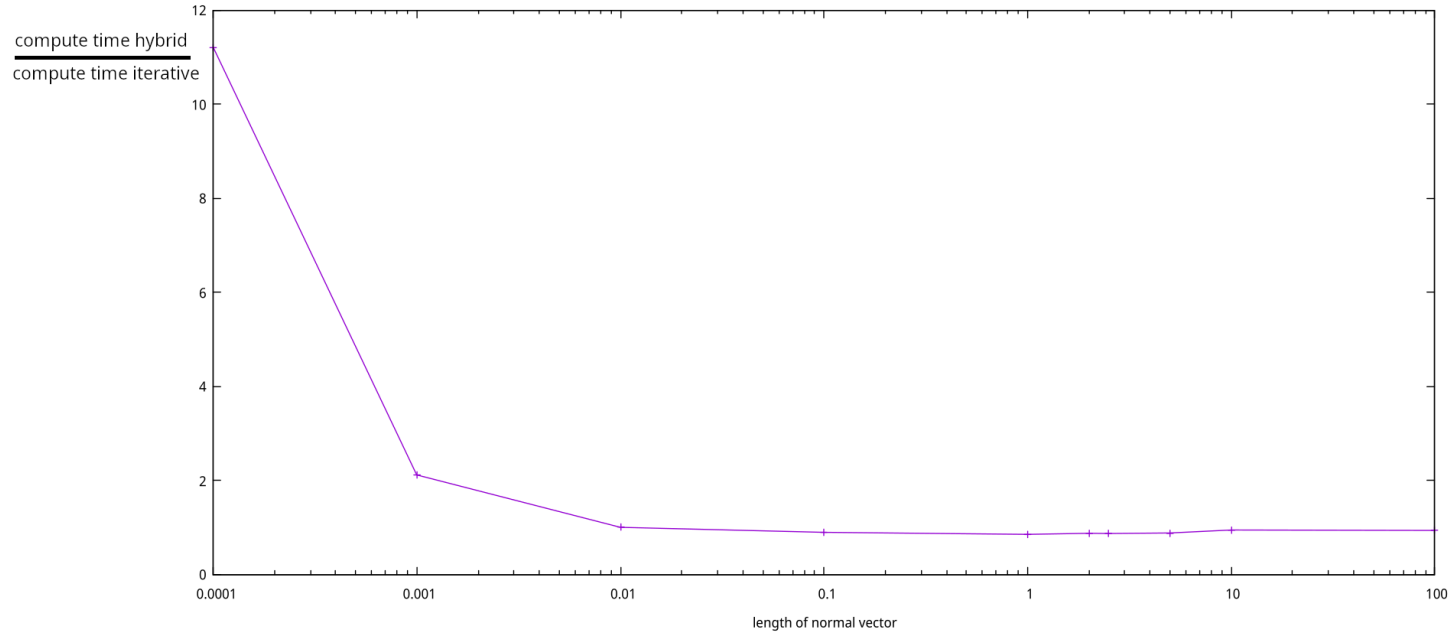

n
ΔZ

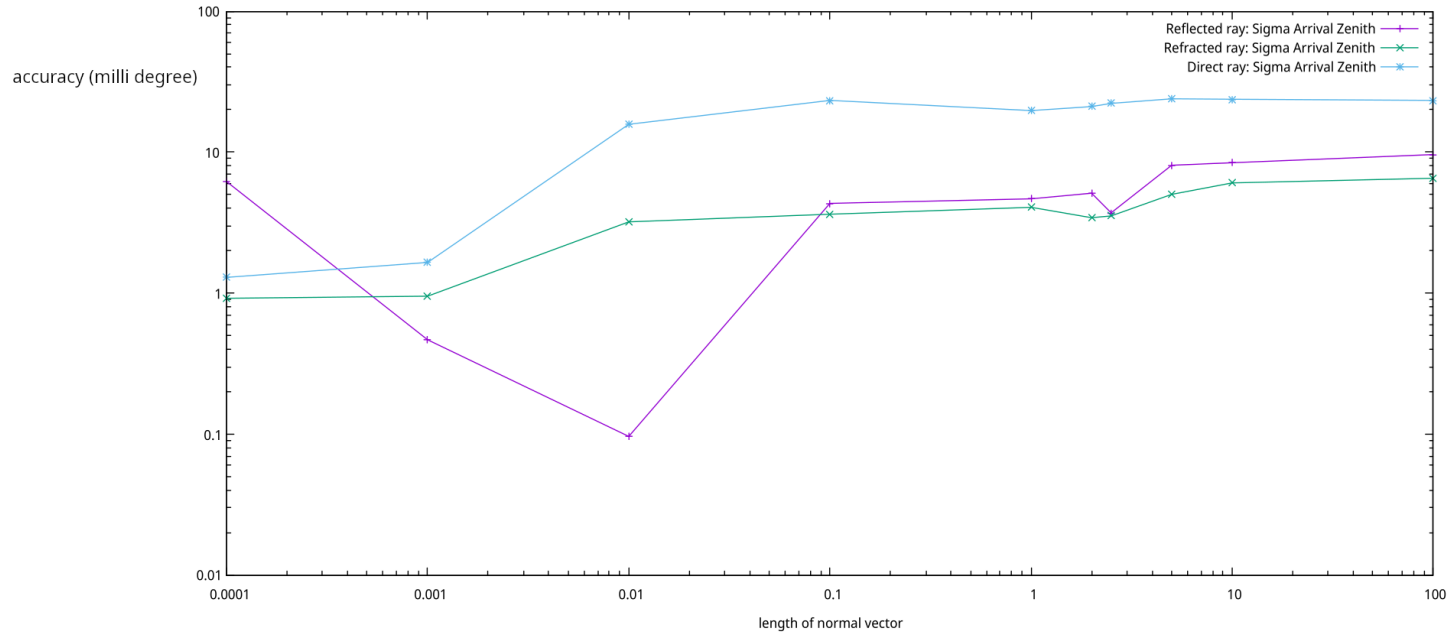

n
n
ΔZ
ΔZ

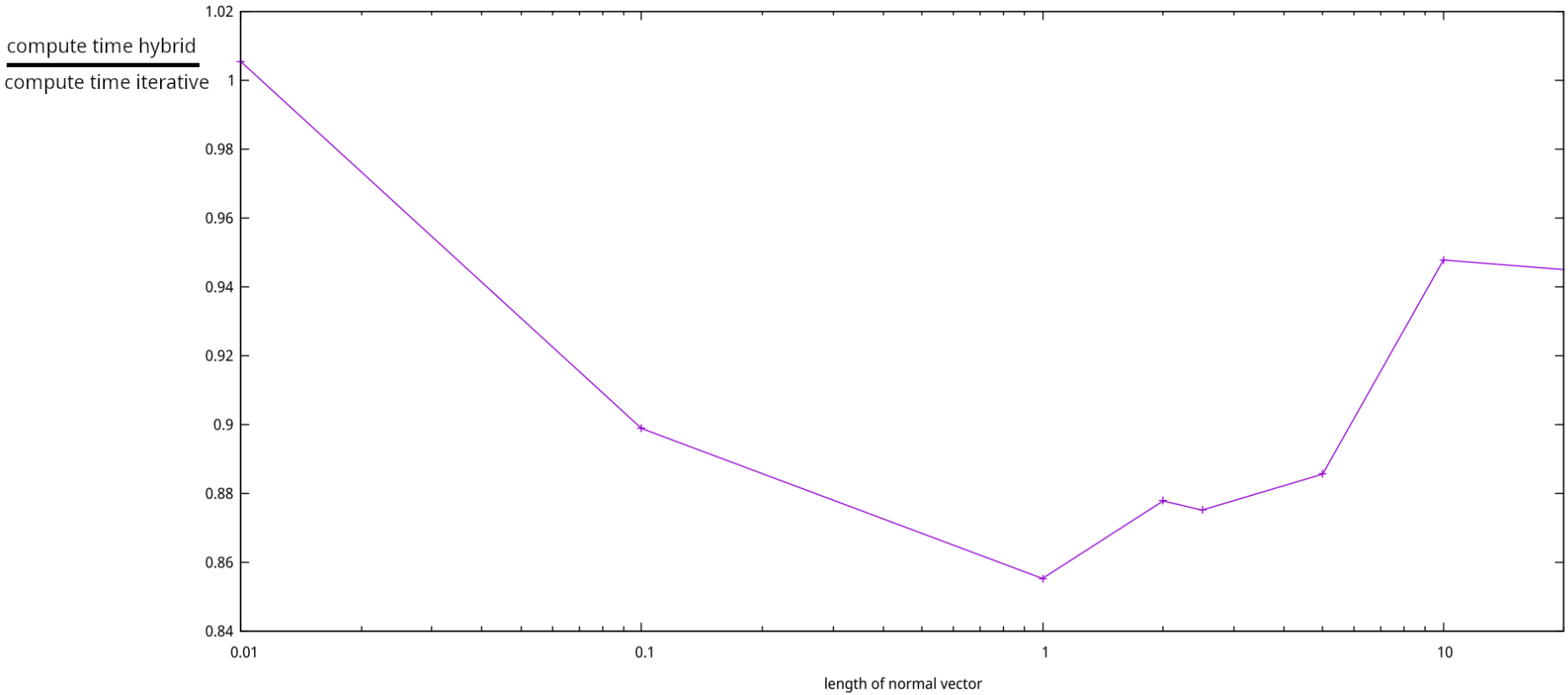

compute time hybrid
compute time iterative
12
10
8
6
4
2
0
0.0001
0.001
0.01
0.1
1
10
100
length of normal vector


compute time hybrid
compute time iterative
12
10
8
6
4
2
0
0.0001
0.001
0.01
0.1
1
10
100
length of normal vector

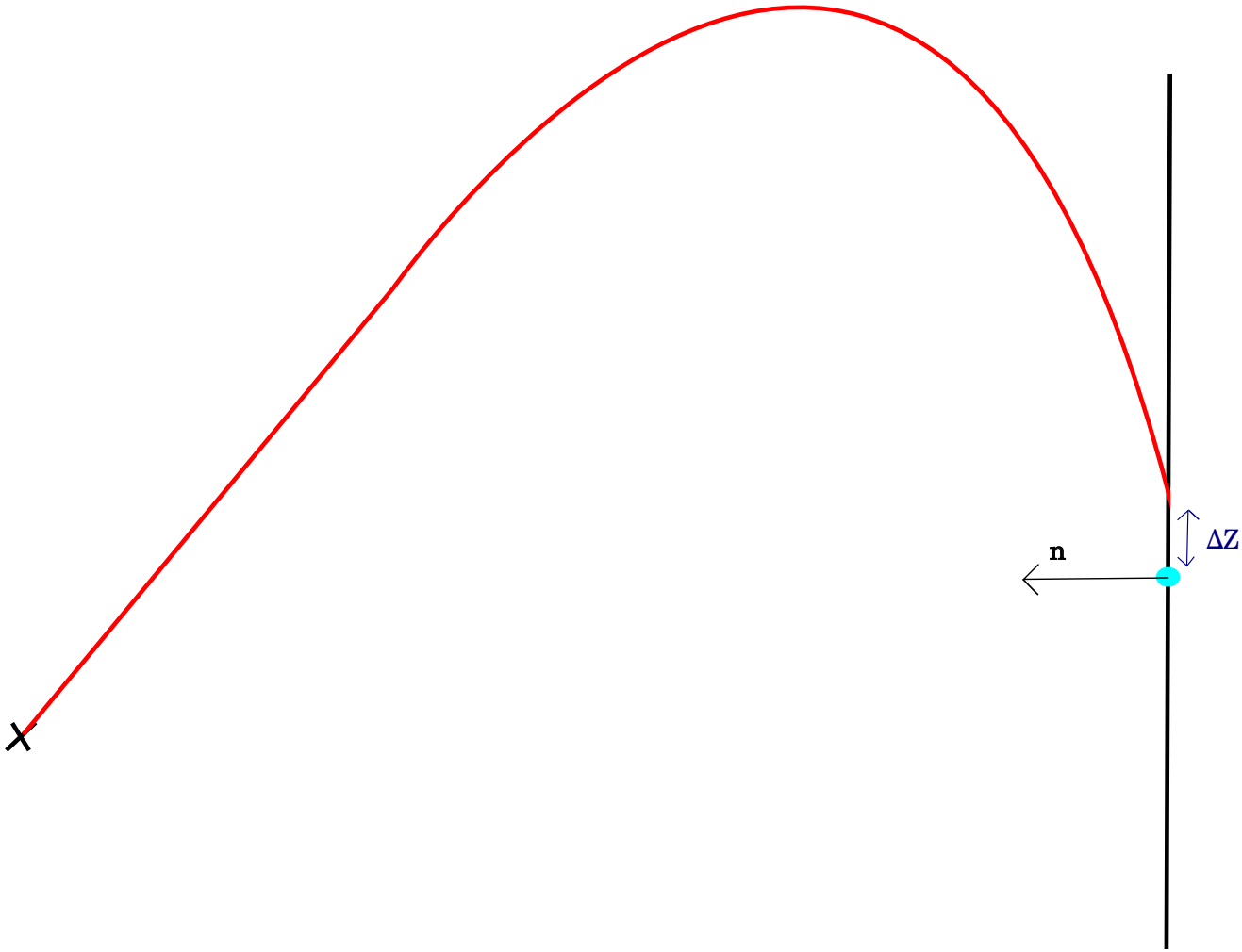

accuracy (ns)
10
1
0.1
0.01
0.001
DirectSigmaTimes
RefractedSigmaTimes
ReflectedSigmaTimes
0.0001
0.001
0.01
0.1
1
10
100
length of normal vector

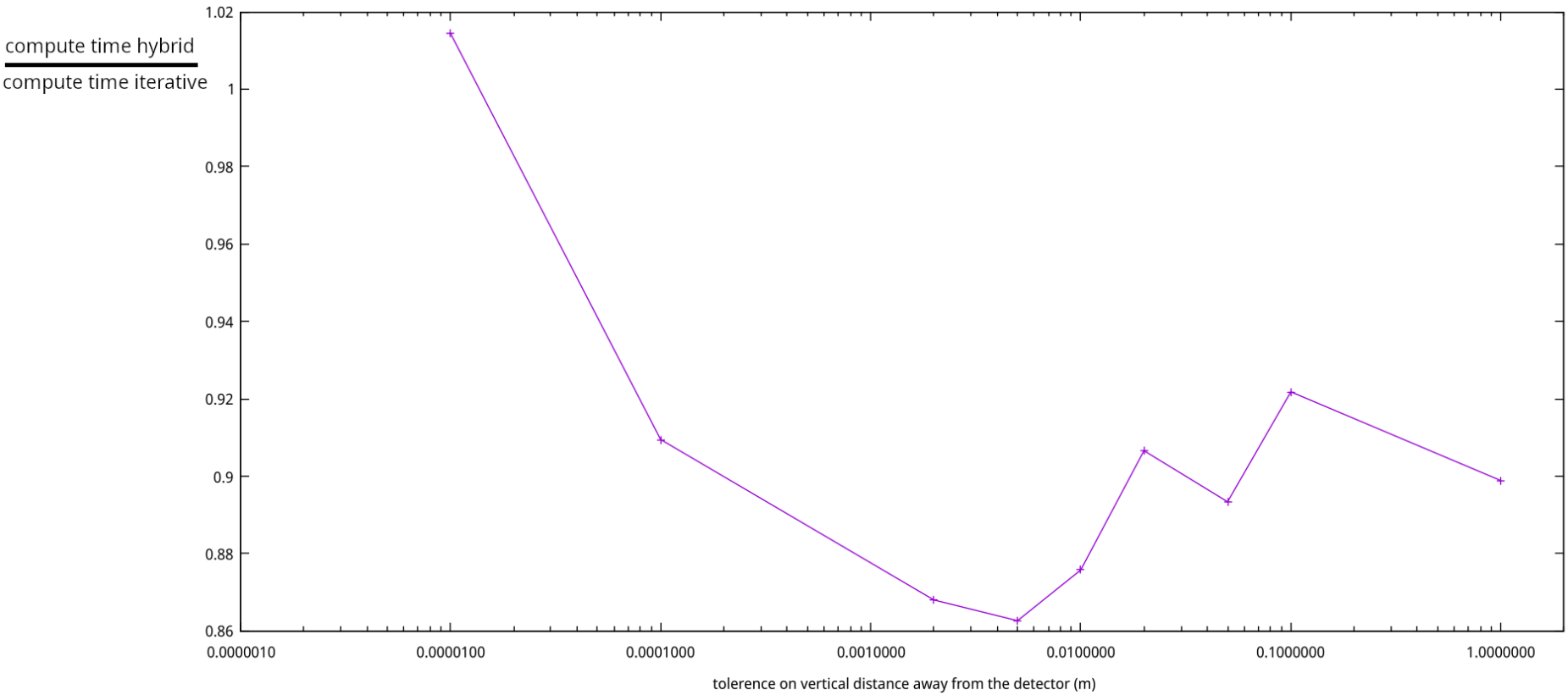

compute time hybrid
compute time iterative
12
10
8
6
4
2
0
0.0001
0.001
0.01
0.1
1
10
100
length of normal vector

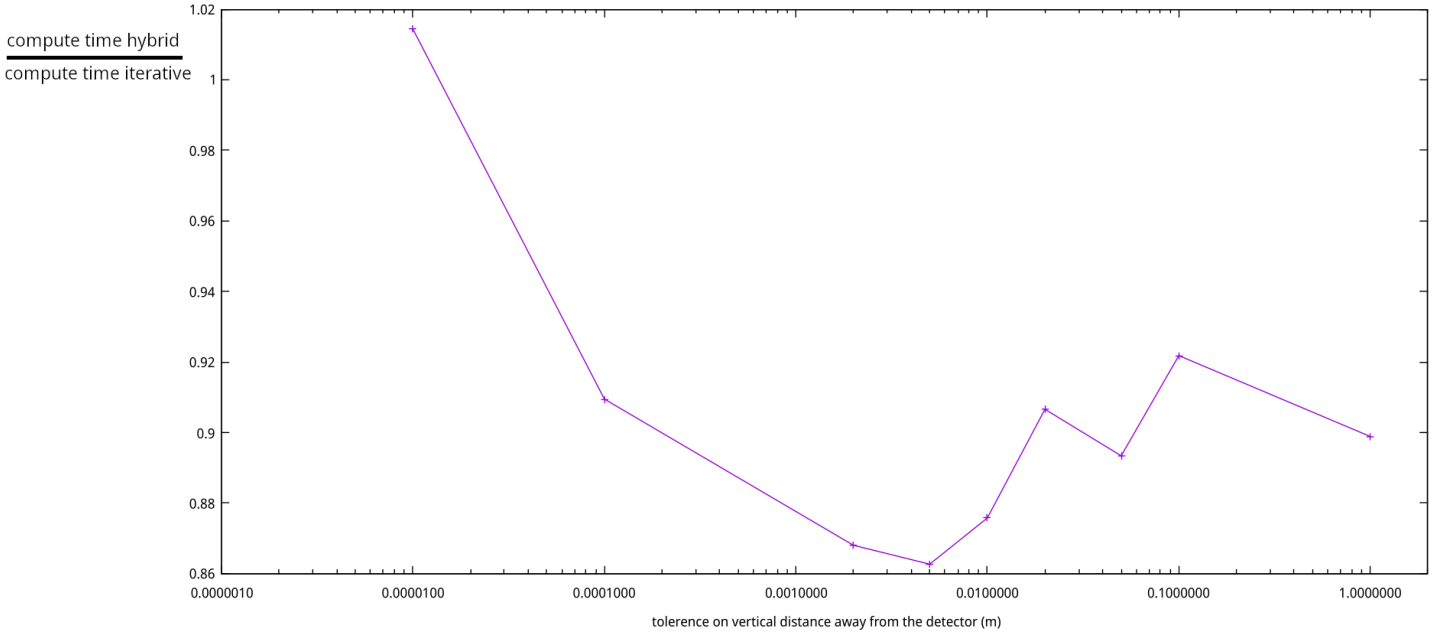

accuracy (milli degree)
Reflected ray: Sigma Arrival Zenith
Refracted ray: Sigma Arrival Zenith
Direct ray: Sigma Arrival Zenith
100
10
1
0.1
0.01
0.0001
0.001
0.01
0.1
1
10
100
length of normal vector

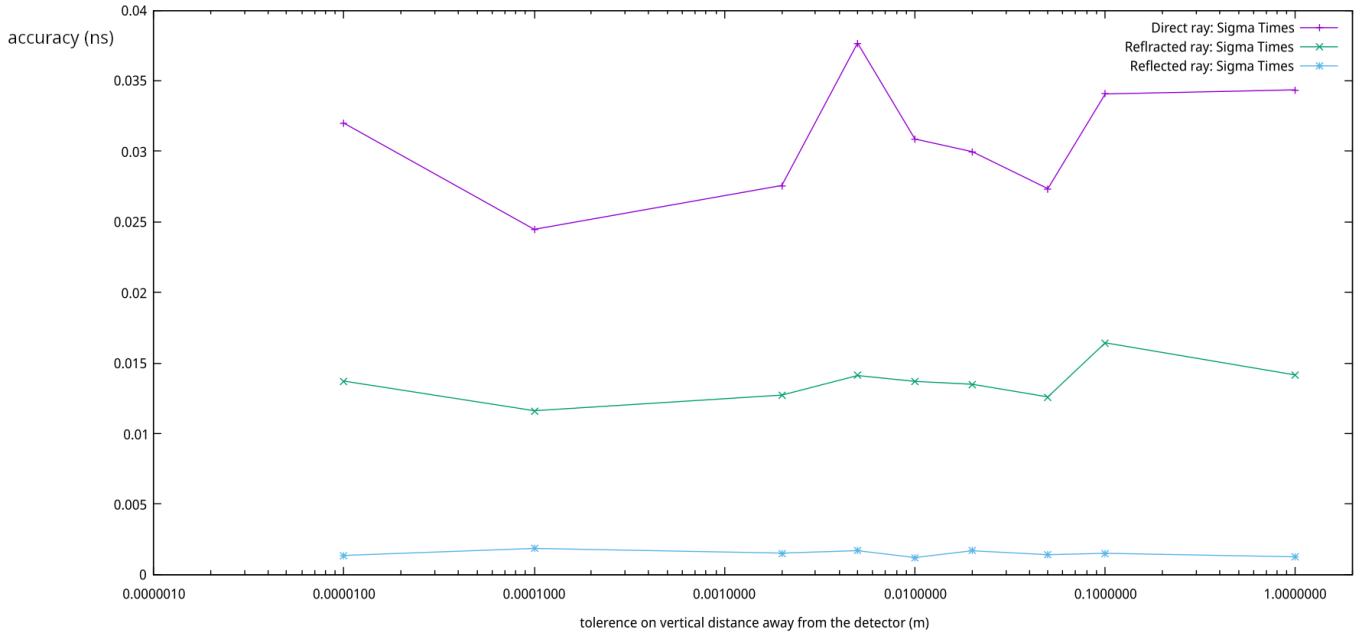

compute time hybrid
compute time iterative
1.02
1
0.98
0.96
0.94
0.92
0.9
0.88
0.86
0.84
0.01
0.1
1
10
length of normal vector

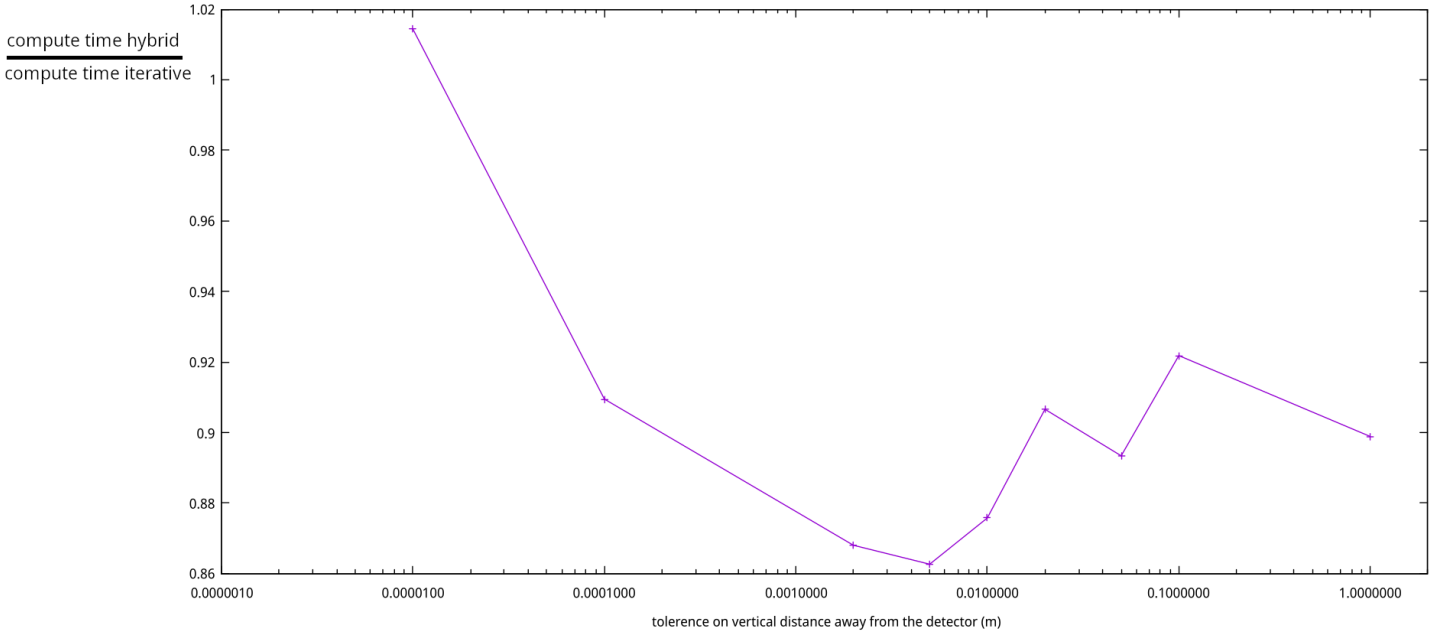
First optimization conclusion:
Take the normal vector length to be 1 meter.

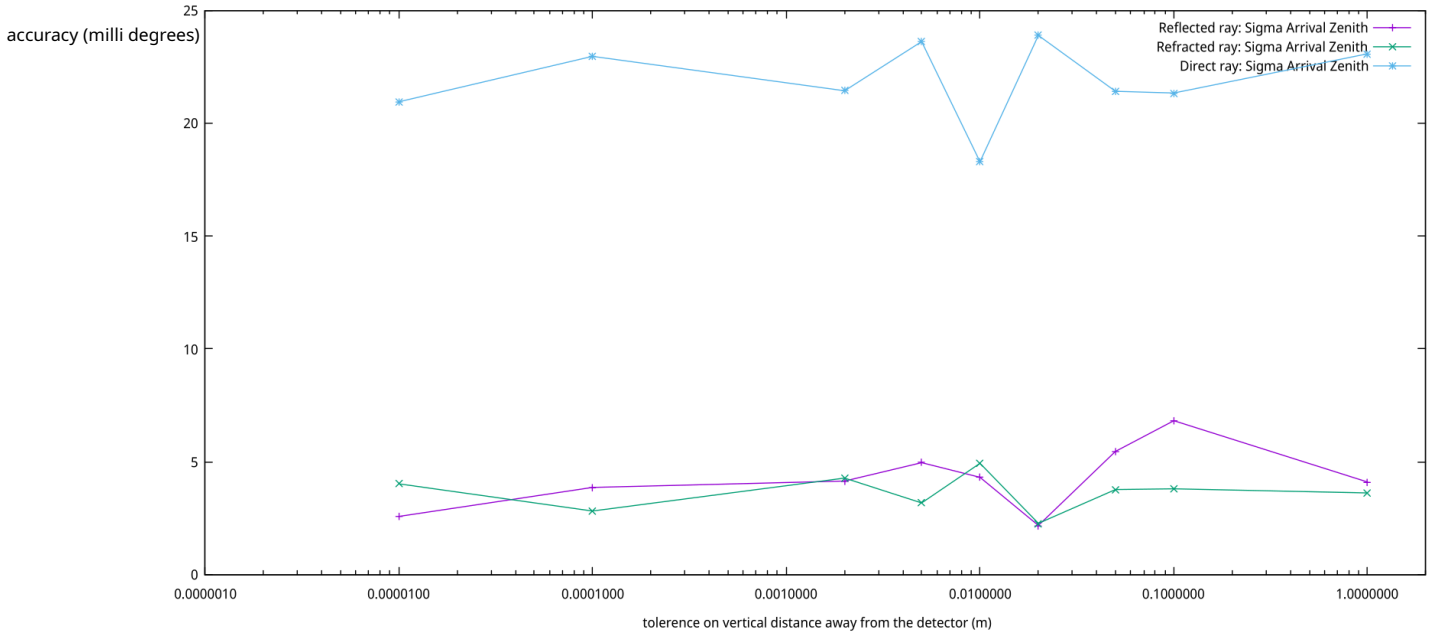

n
ΔZ


compute time hybrid
compute time iterative
1.02
1
0.98
0.96
0.94
0.92
0.9
0.88
0.86
0.0000010
0.0000100
0.0001000
0.0010000
0.0100000
0.1000000
1.0000000
tolerence on vertical distance away from the detector (m)


compute time hybrid
compute time iterative
1.02
1
0.98
0.96
0.94
0.92
0.9
0.88
0.86
0.0000010
0.0000100
0.0001000
0.0010000
0.0100000
0.1000000
1.0000000
tolerence on vertical distance away from the detector (m)

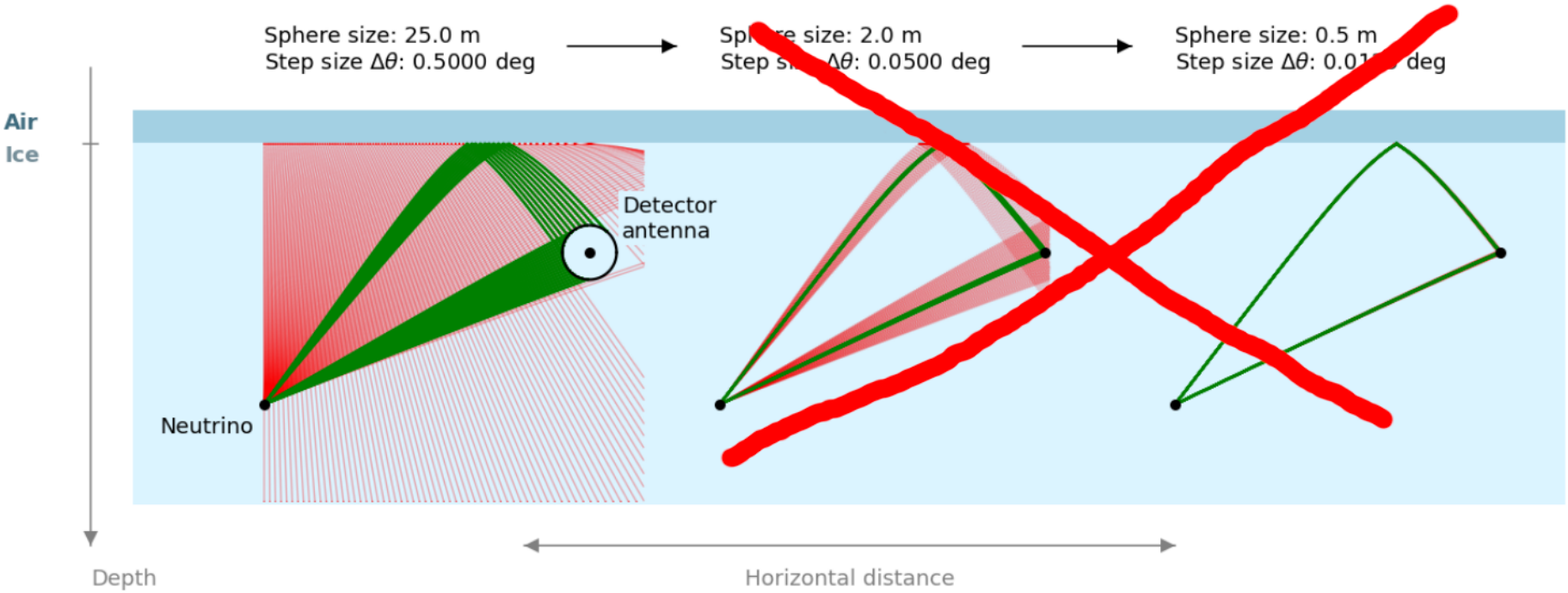

accuracy (ns)
Direct ray: Sigma Times
Reflracted ray: Sigma Times
Reflected ray: Sigma Times
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0.0000010
0.0000100
0.0001000
0.0010000
0.0100000
0.1000000
1.0000000
tolerence on vertical distance away from the detector (m)

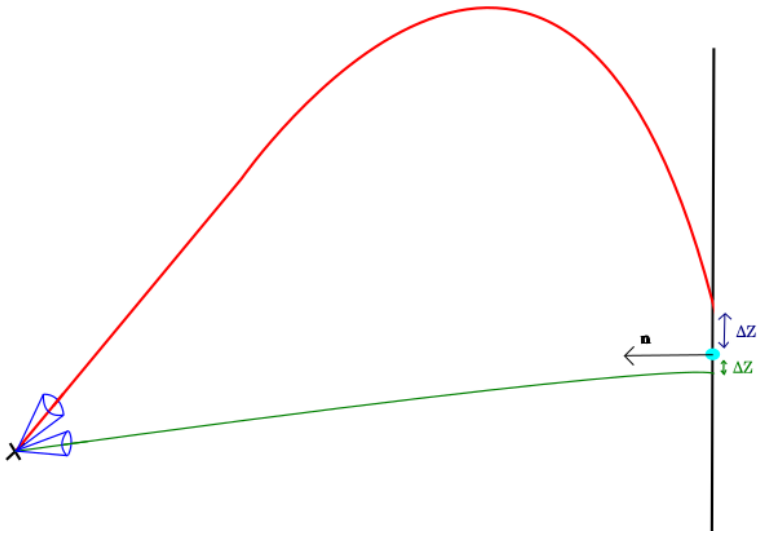

compute time hybrid
compute time iterative
1.02
1
0.98
0.96
0.94
0.92
0.9
0.88
0.86
0.0000010
0.0000100
0.0001000
0.0010000
0.0100000
0.1000000
1.0000000
tolerence on vertical distance away from the detector (m)


accuracy (milli degrees)
Reflected ray: Sigma Arrival Zenith
Refracted ray: Sigma Arrival Zenith
Direct ray: Sigma Arrival Zenith
25
20
15
10
5
0
0.0000010
0.0000100
0.0001000
0.0010000
0.0100000
0.1000000
1.0000000
tolerence on vertical distance away from the detector (m)

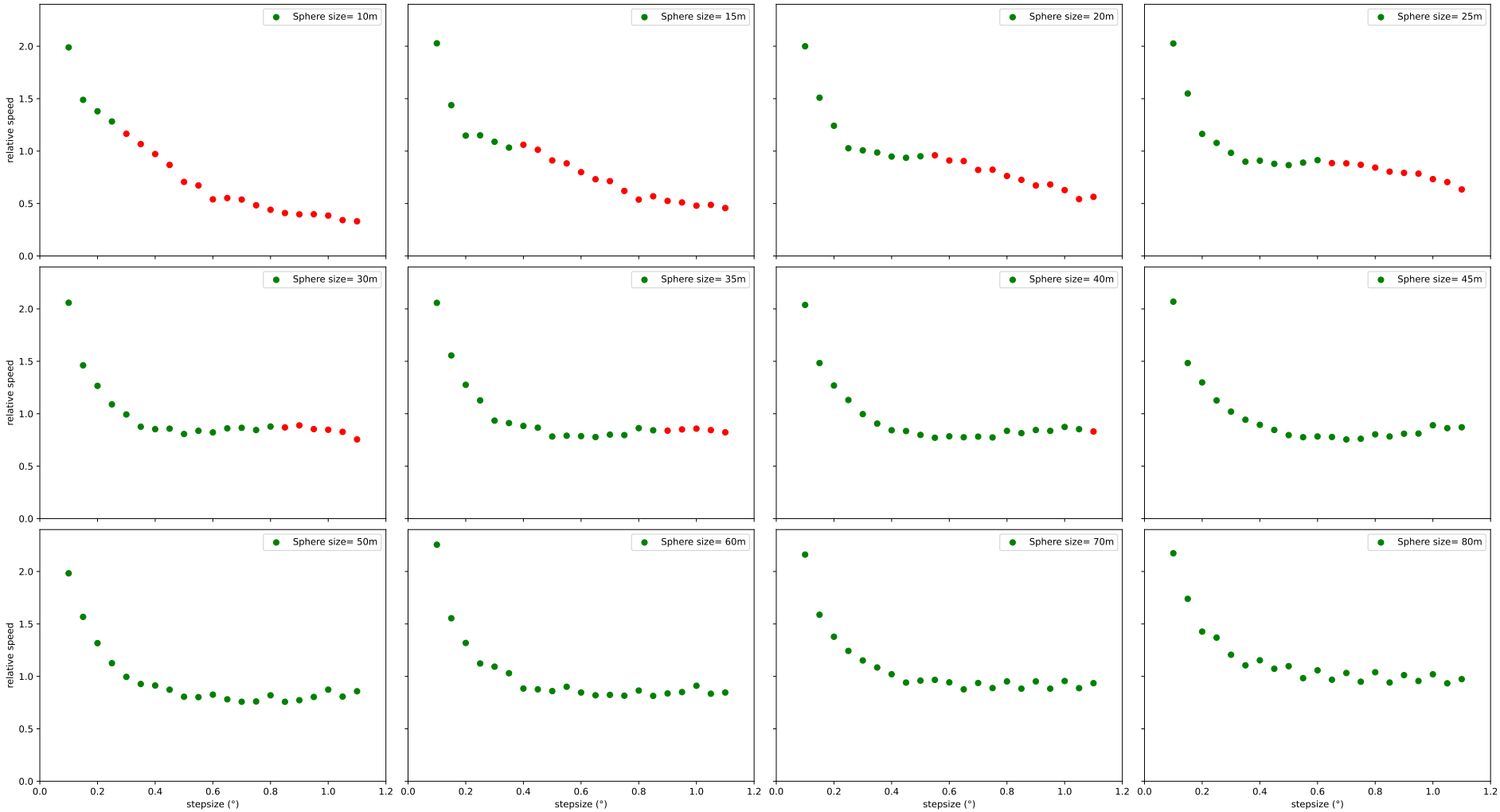
Second optimization conclusion:
Take ztol to be 0.05 m.

Sphere Size & Step Size

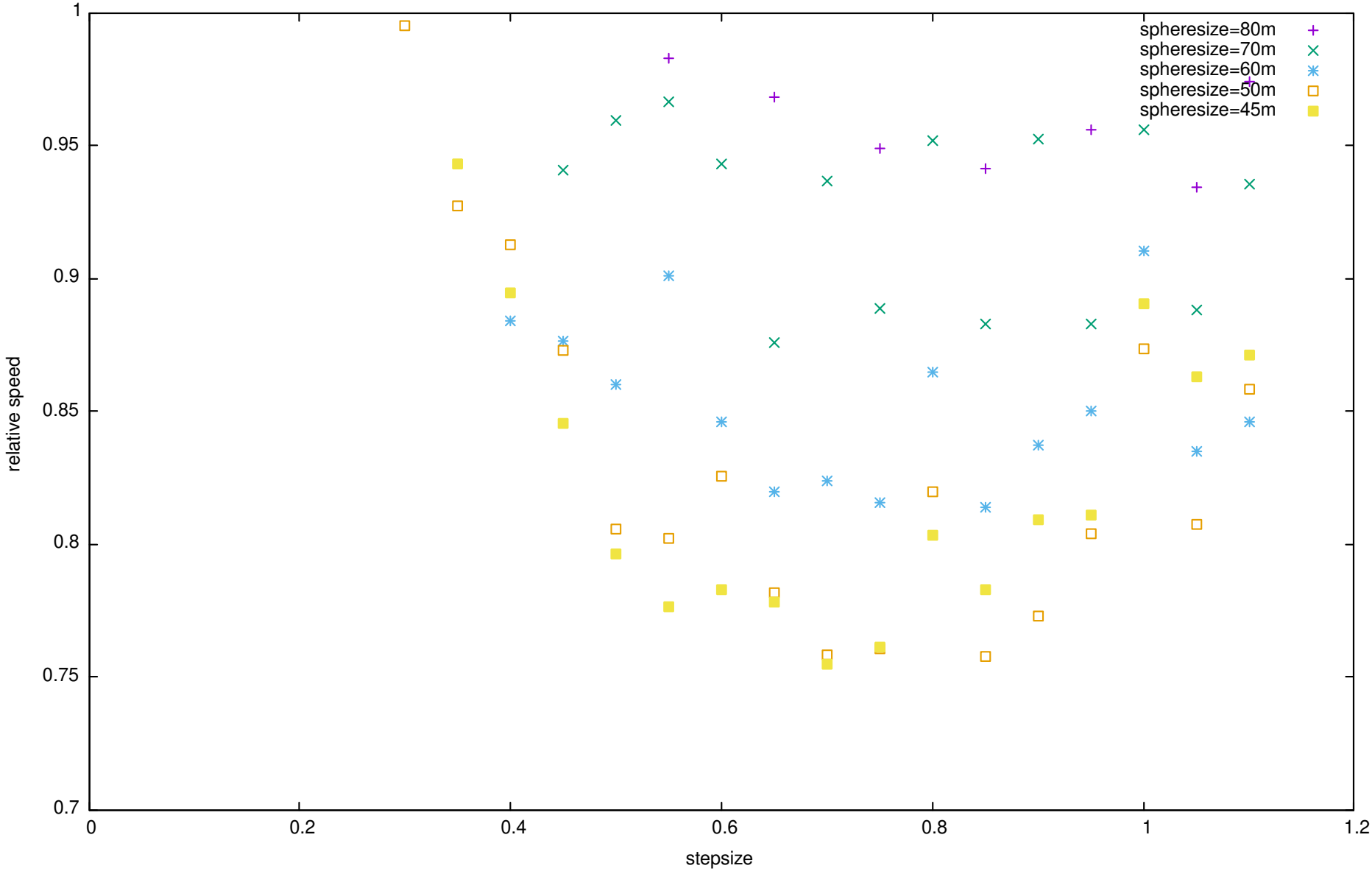




Sphere Size & Step Size



Sphere Size & Step Size



Final Result

- norm = 1m
- ztol = 0.05m
- Sphere size = 45m
- step size = 0.7°

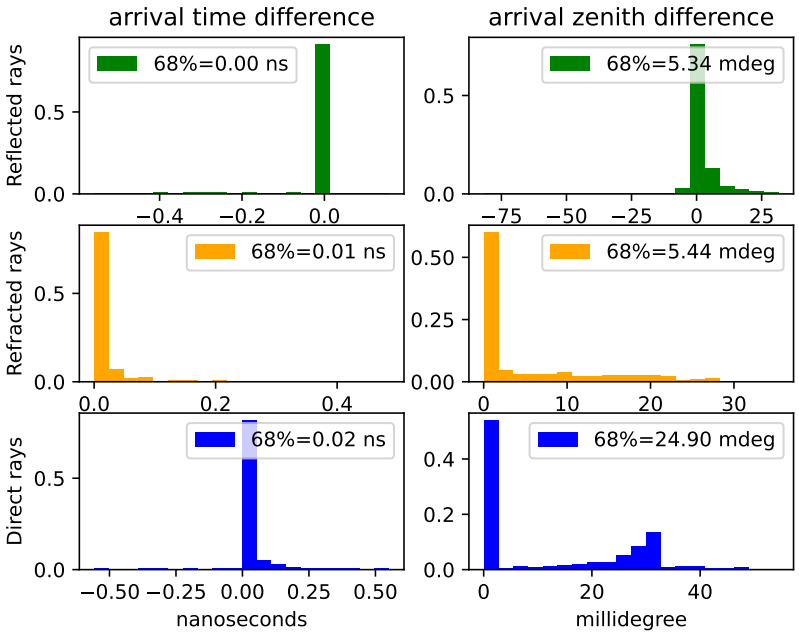


Figure: Hybrid

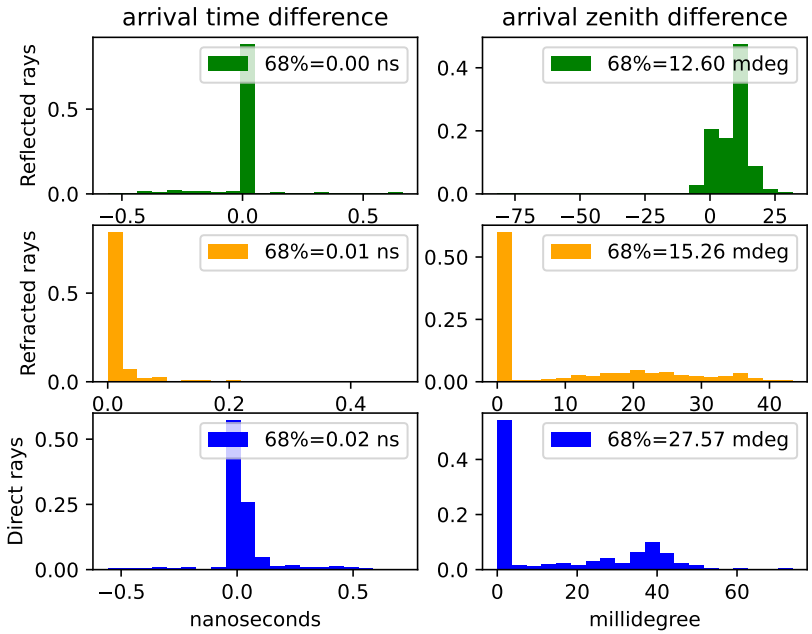


Figure: Iterative

- iterative :1.627s $\implies$ 0.61 $\frac{\text{computations}}{s}$
- hybrid : 1.226s $\implies$ 0.82 $\frac{\text{computations}}{s}$ (33.7% faster)
- analytic: 9.719e-05 seconds $\implies$ 10289 $\frac{\text{computations}}{s}$ (632298% faster)