Hybrid Ray Tracer

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what?

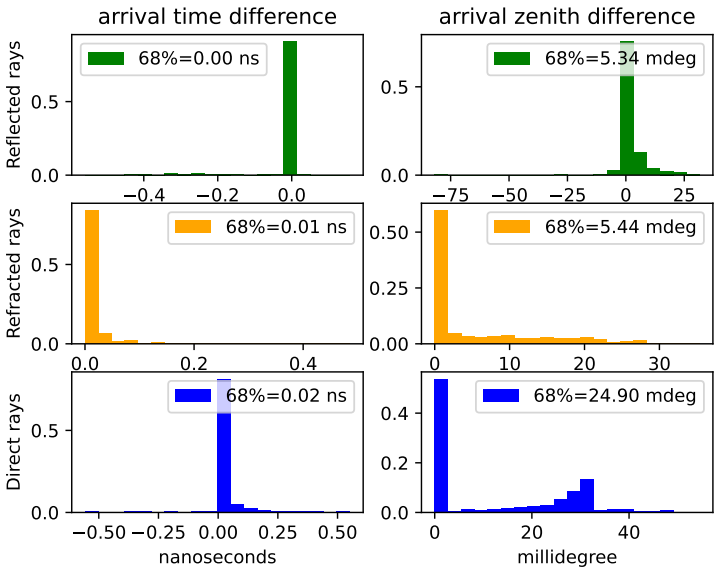


Figure: Hybrid

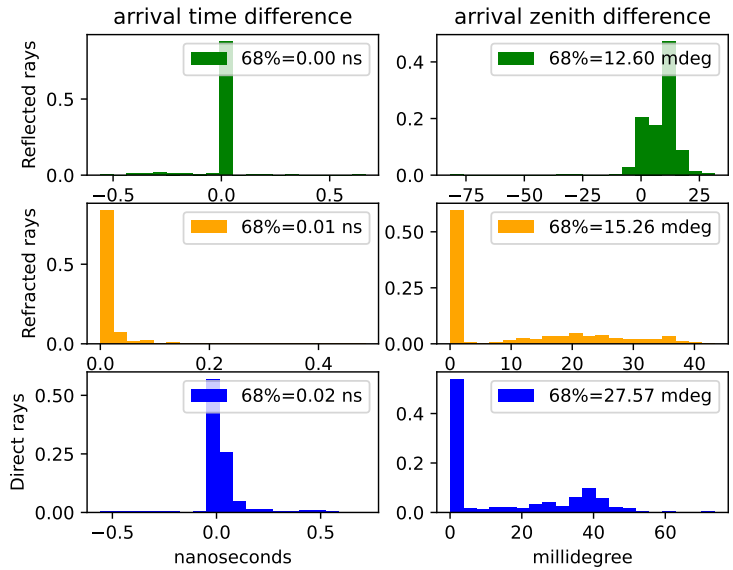


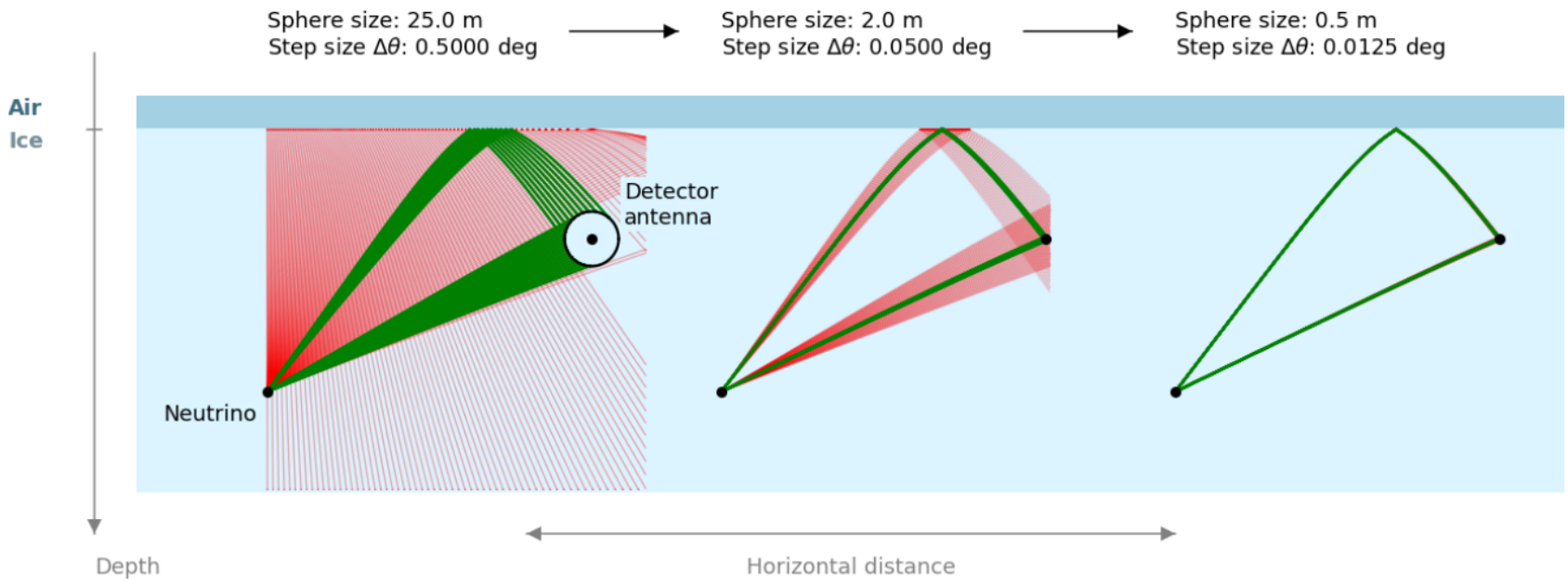
Figure: Iterative

Why?

- Complex ice models needed
- full path might be needed

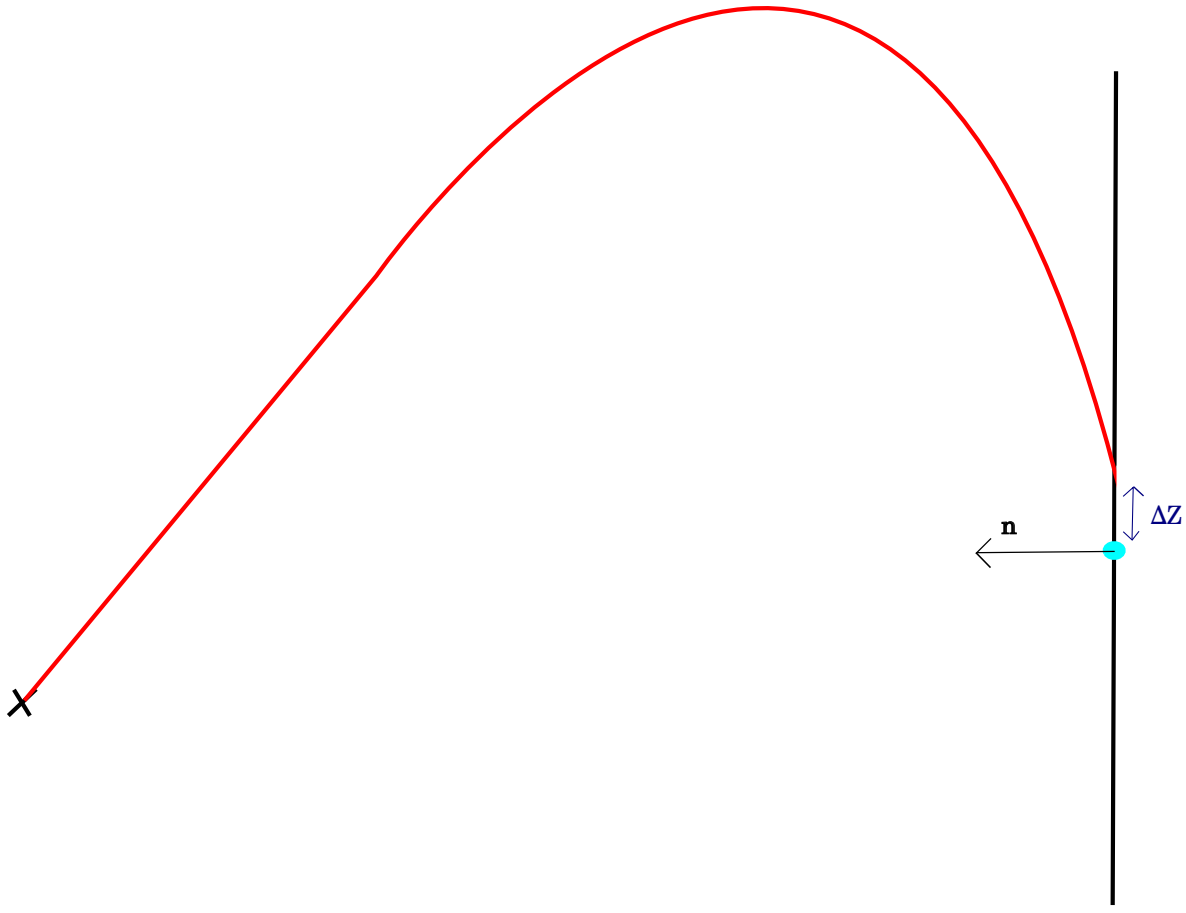
1. How the iterative ray tracer works
2. previous attempt to make it better
3. my attempt to make it better
4. optimisation of my attempt (the hybrid raytracer)
5. final results

Iterative ray tracer

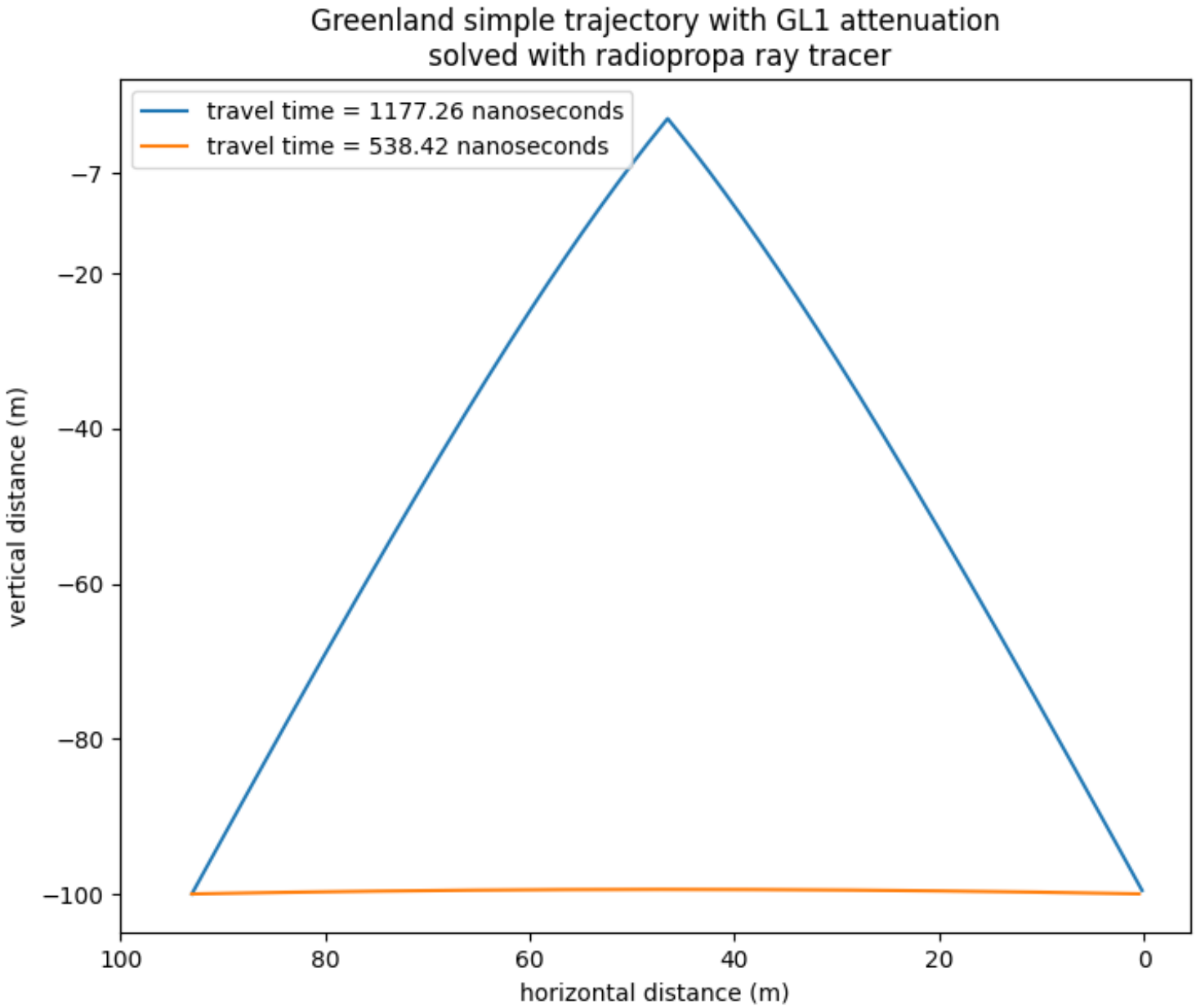


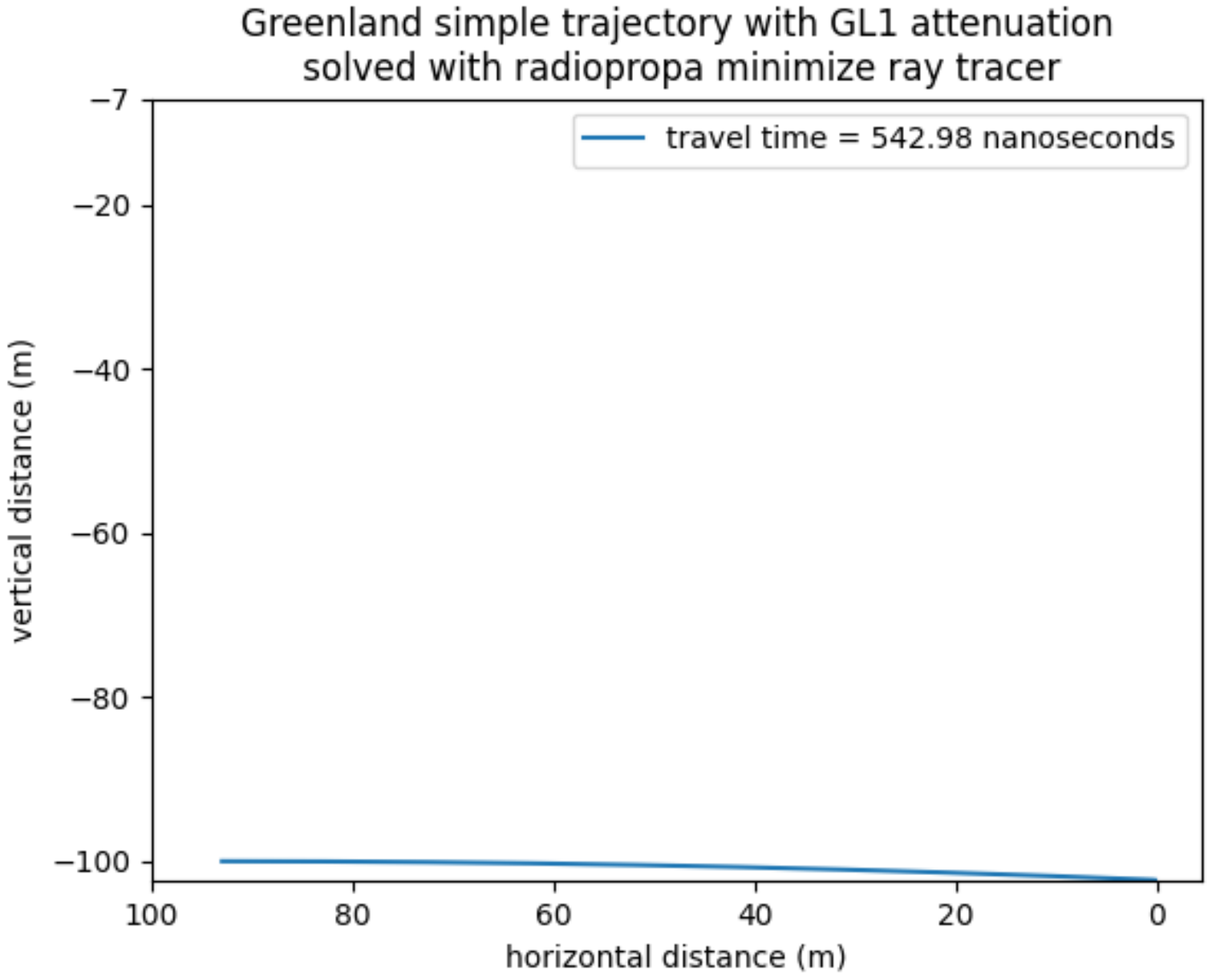
Non optimal $\rightarrow$ scipy.optimize.minimize

$\Longrightarrow$ minimizer

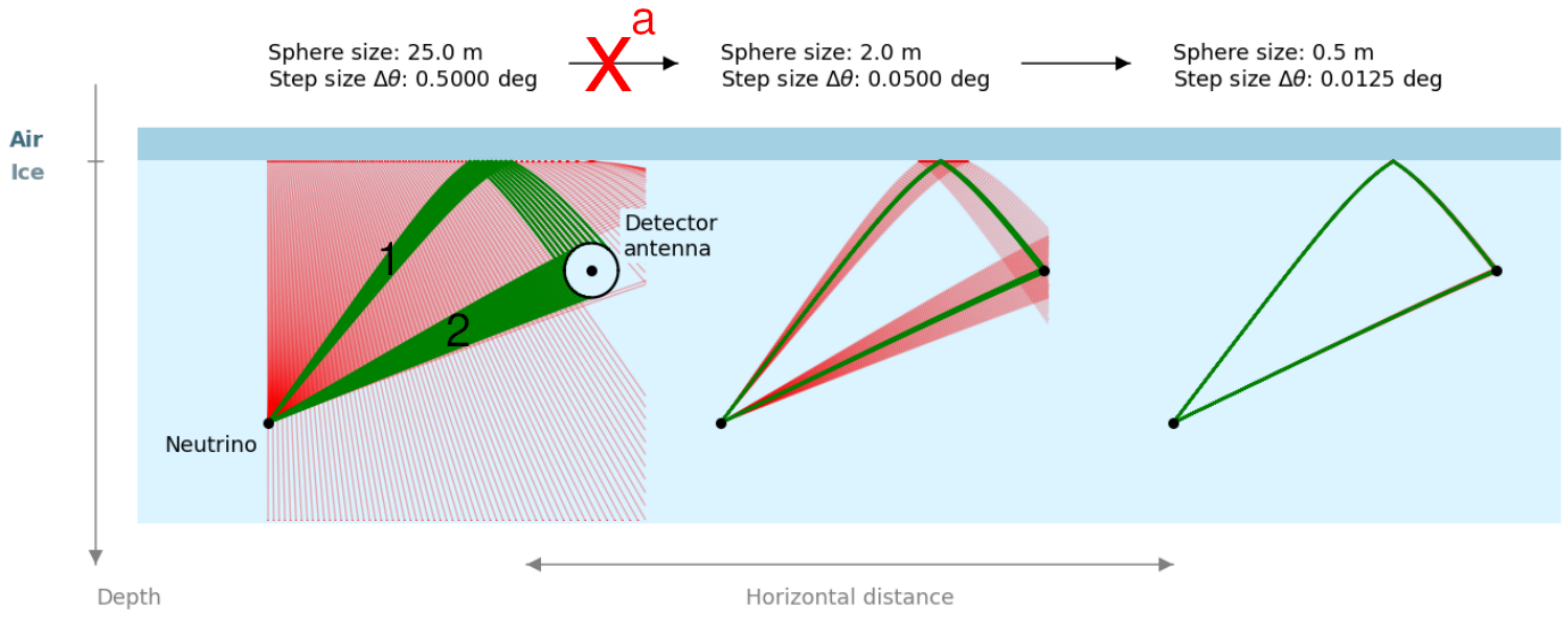

n
ΔZ

Problem: can't find the intervals for certain cases

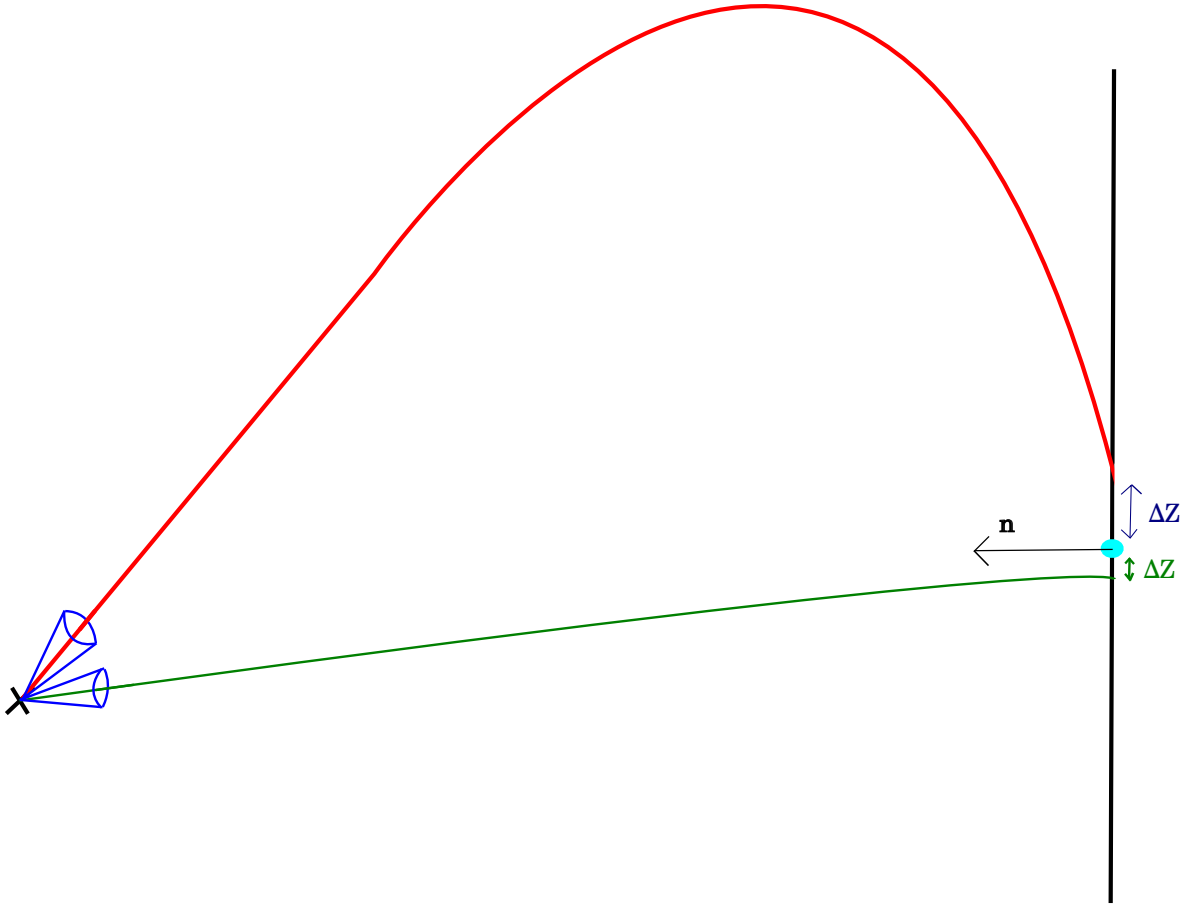

Greenland simple trajectory with GL1 attenuation
solved with radiopropa ray tracer
travel time = 1177.26 nanoseconds
travel time = 538.42 nanoseconds
−7
−20
−40
−60
−80
−100
vertical distance (m)
100
80
60
40
20
0
horizontal distance (m)

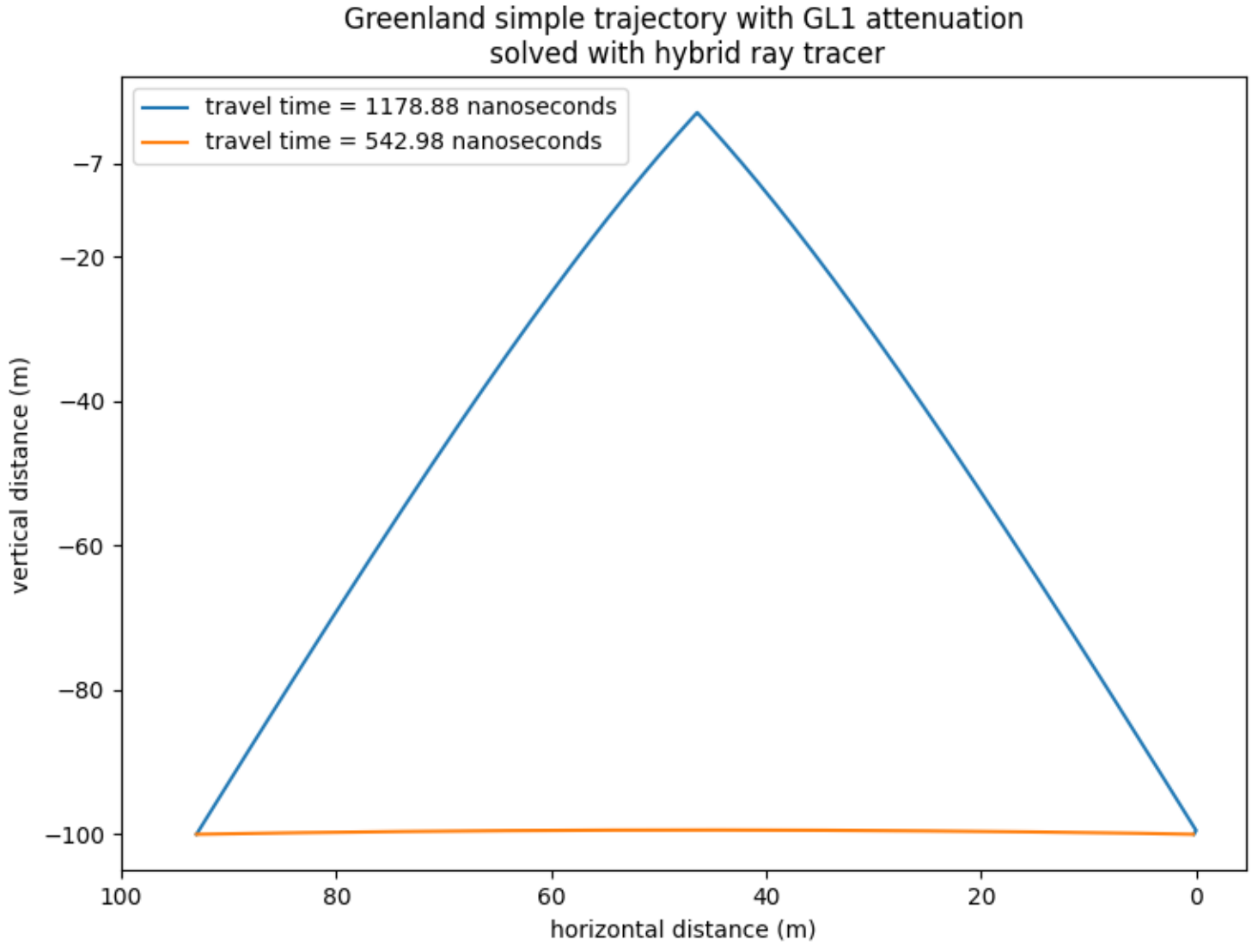

Greenland simple trajectory with GL1 attenuation
solved with radiopropa minimize ray tracer
travel time = 542.98 nanoseconds
vertical distance (m)
−7
−20
−40
−60
−80
−100
100
80
60
40
20
0
horizontal distance (m)

My solution



a process is broken out of as 2 distinct launch regions (region 1 & 2) are found.


n
ΔZ
ΔZ


Greenland simple trajectory with GL1 attenuation
solved with hybrid ray tracer
travel time = 1178.88 nanoseconds
travel time = 542.98 nanoseconds
−7
−20
−40
−60
−80
−100
vertical distance (m)
100
80
60
40
20
0
horizontal distance (m)

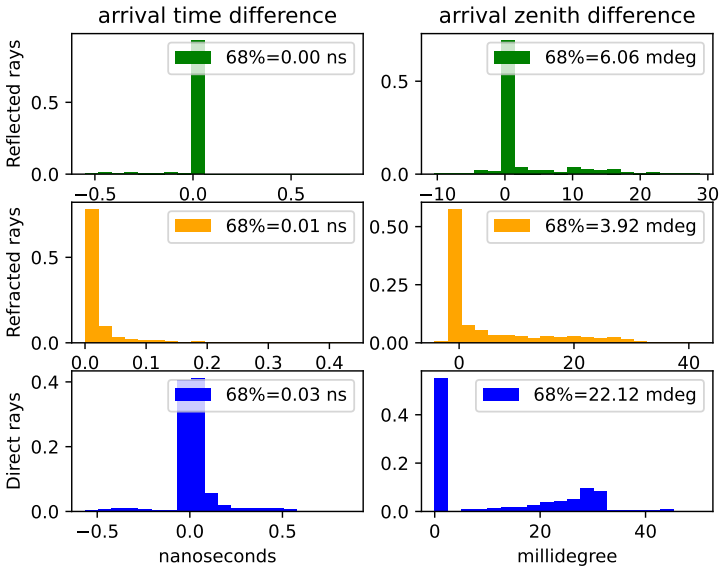


Figure: Hybrid

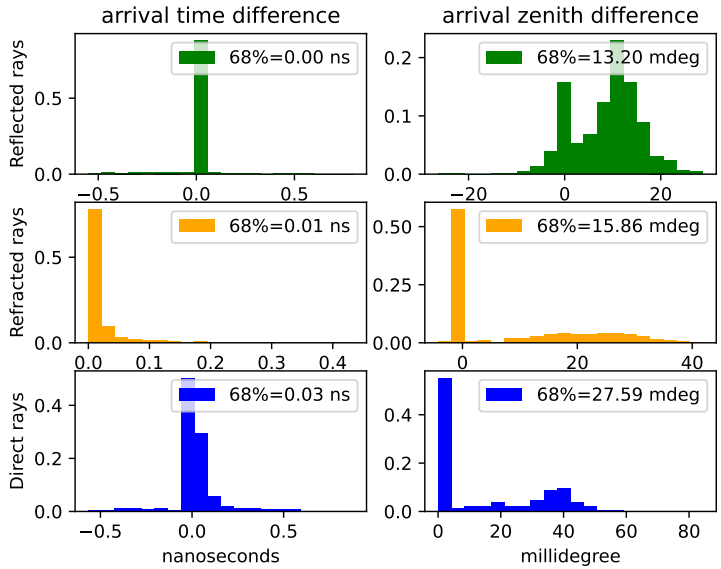
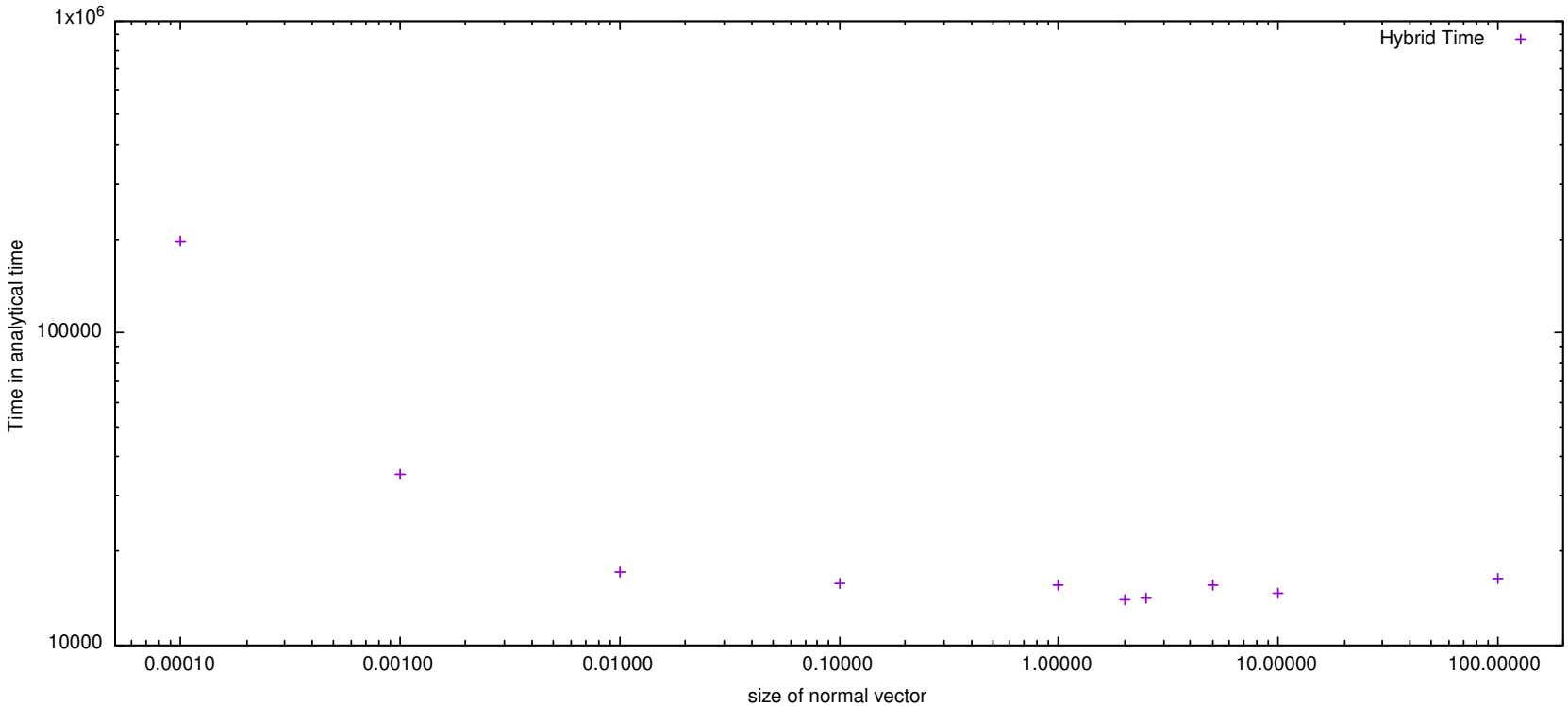


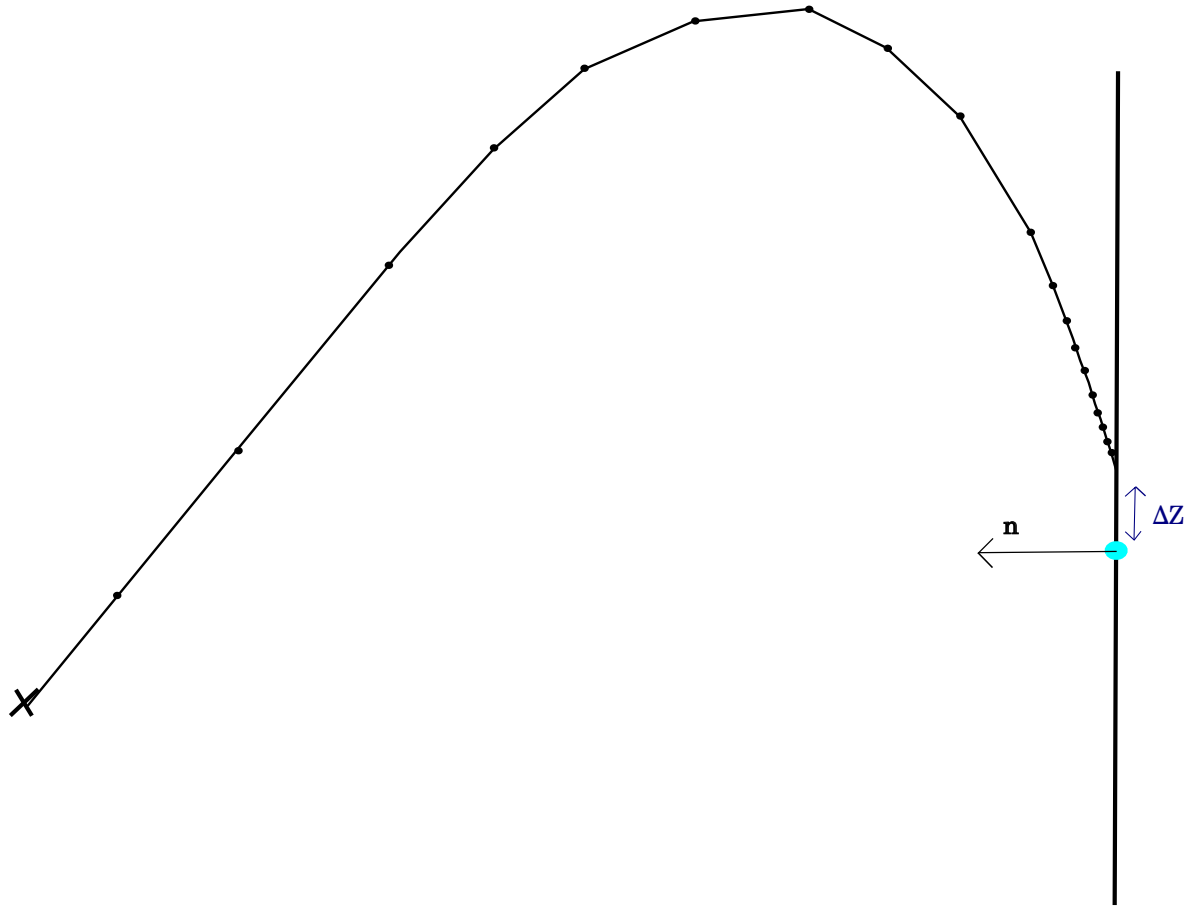
Figure: Iterative

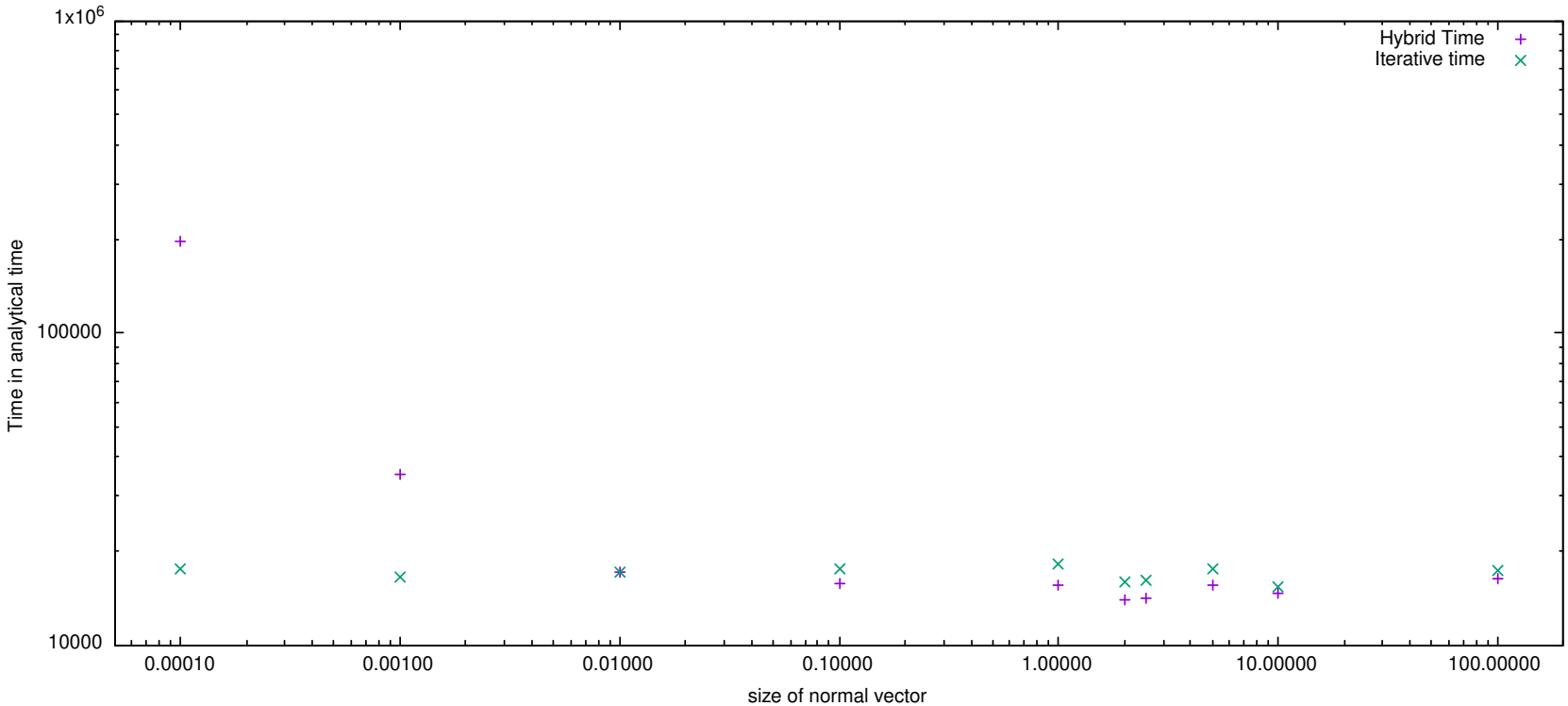
Whilst $\approx$ 15% faster

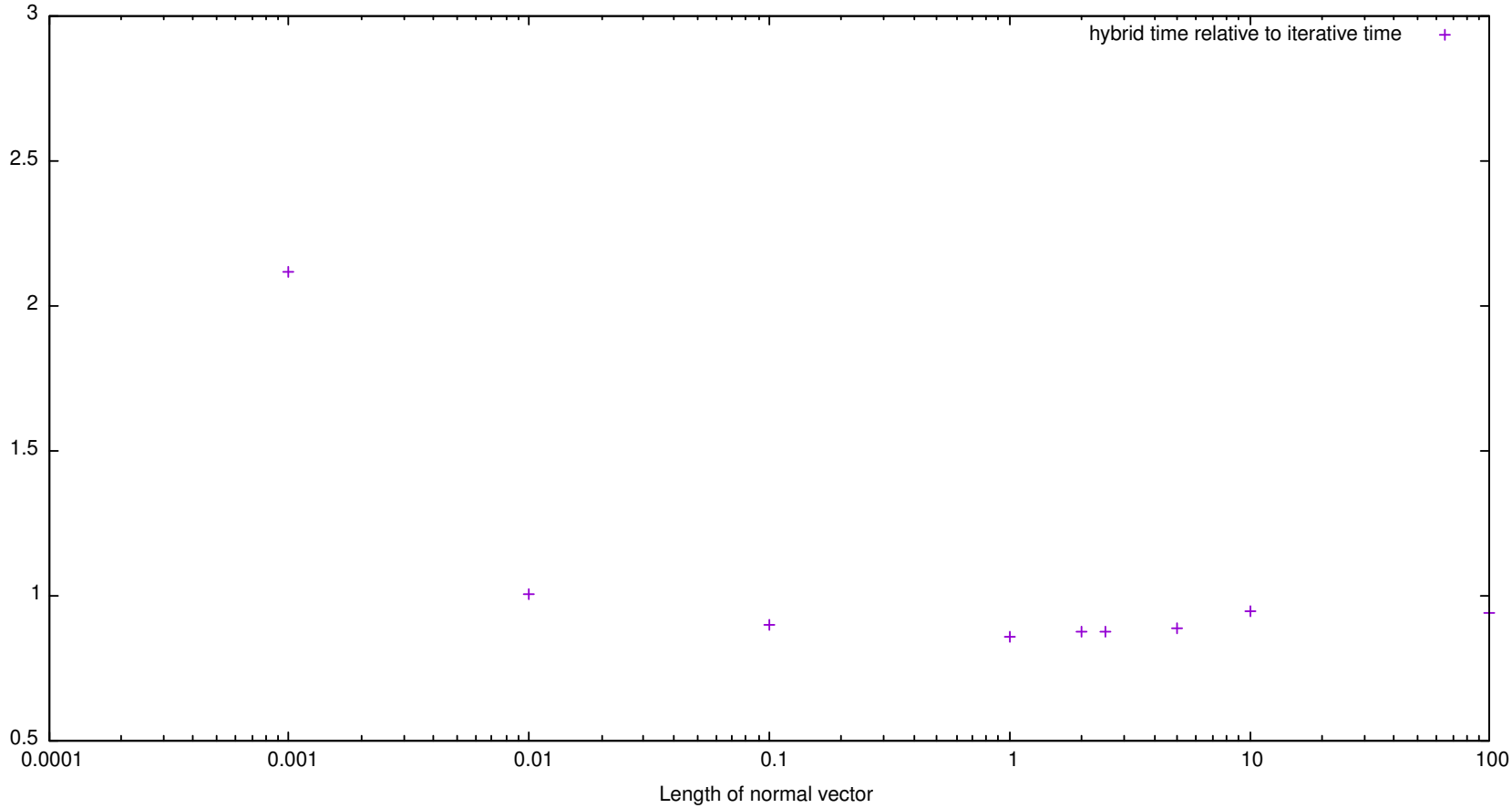
Optimization

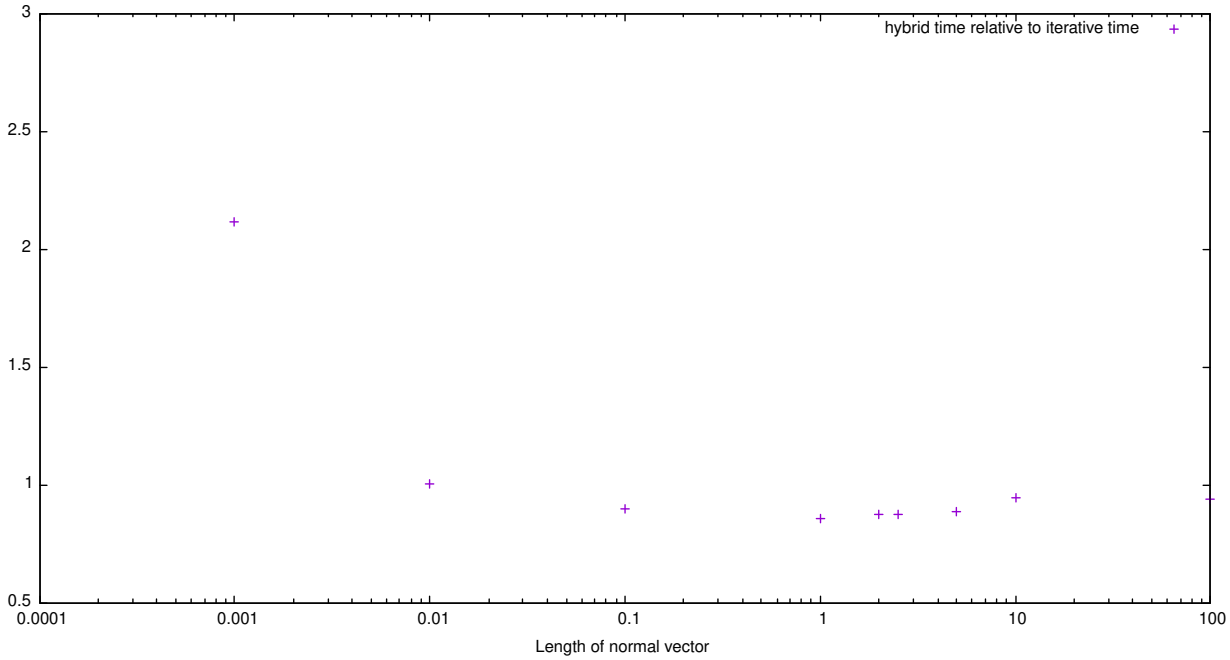
Length of the normal vector:

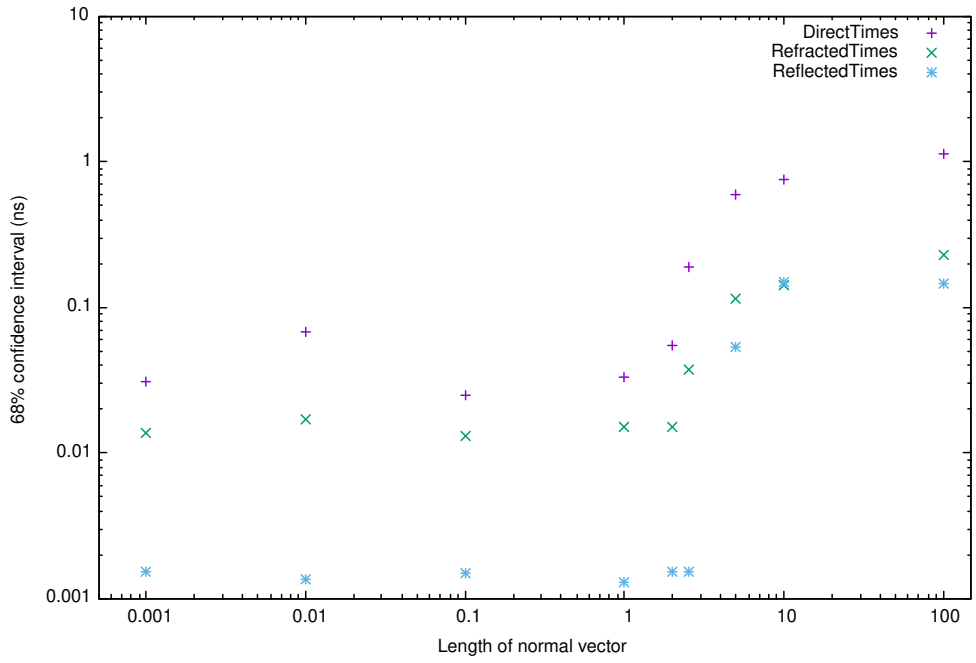


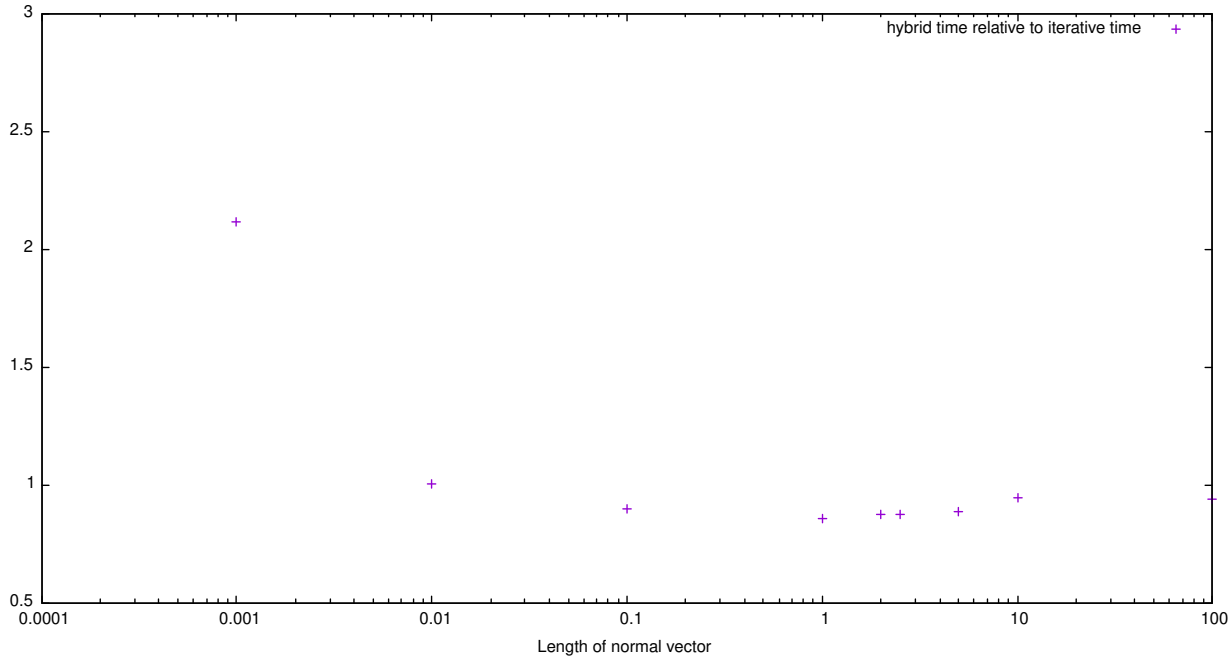

n
ΔZ

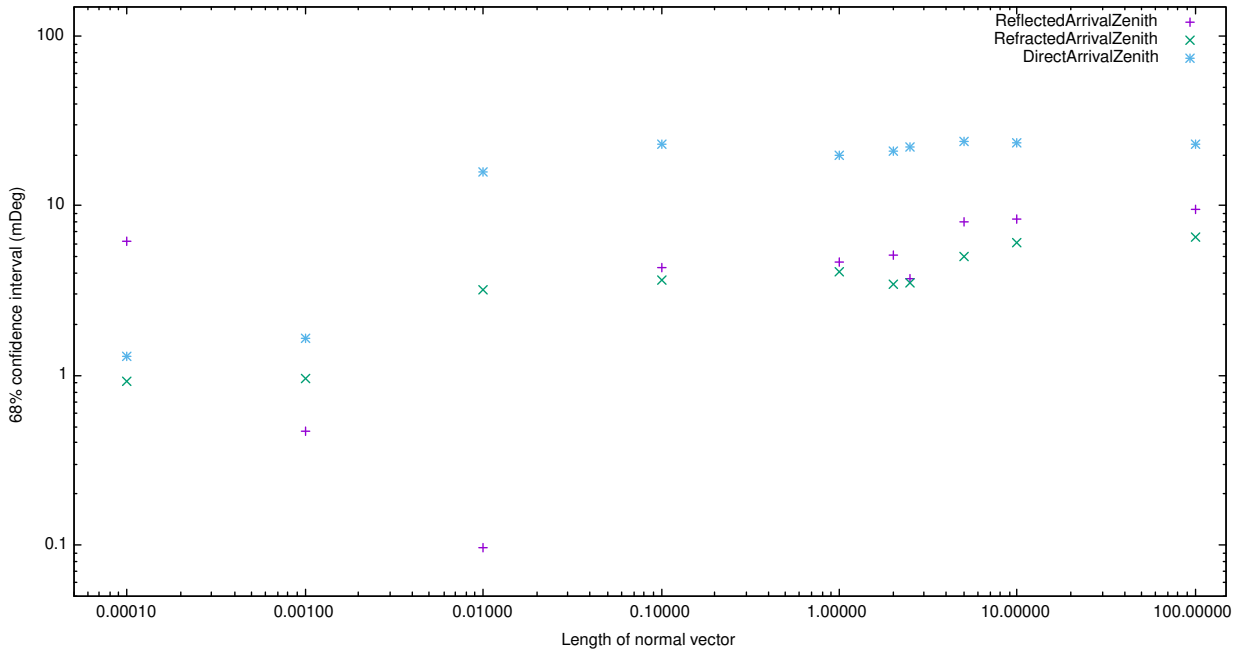

1x10^6
100000
10000
Time in analytical time
0.00010
0.00100
0.01000
0.10000
1.00000
10.00000
100.00000
size of normal vector
Hybrid Time
Iterative time

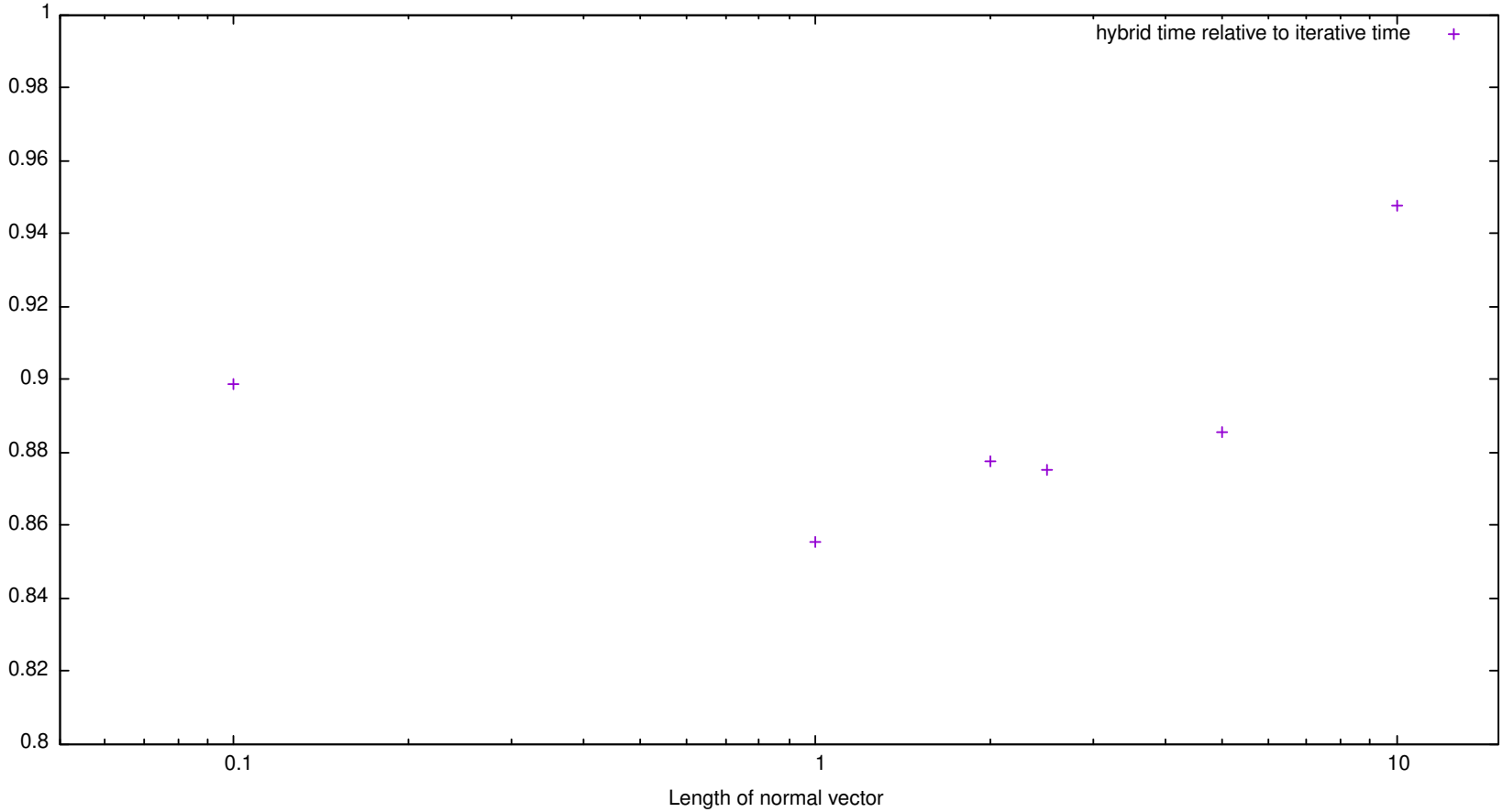

hybrid time relative to iterative time
3
2.5
2
1.5
1
0.5
0.0001
0.001
0.01
0.1
1
10
100
Length of normal vector


hybrid time relative to iterative time
3
2.5
2
1.5
1
0.5
0.0001
0.001
0.01
0.1
1
10
100
Length of normal vector

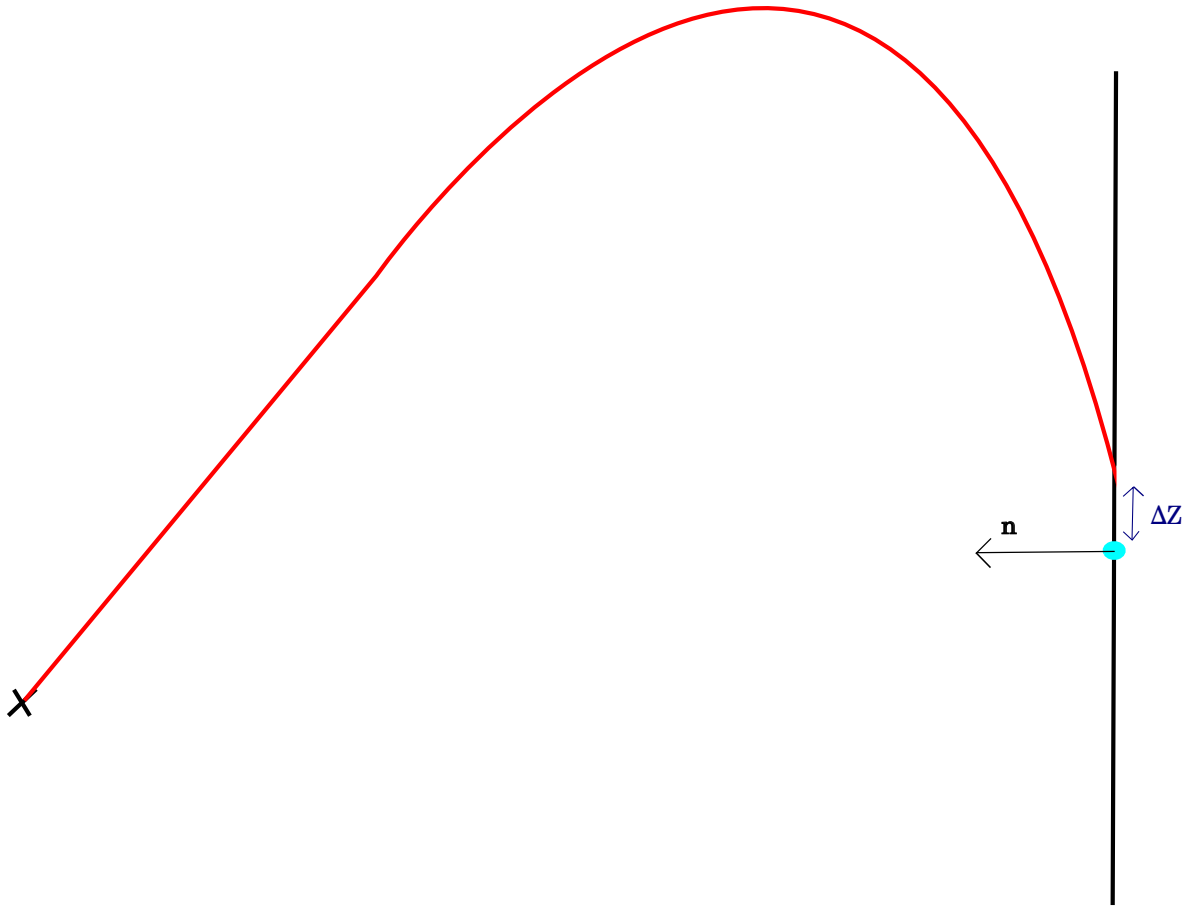

DirectTimes
RefractedTimes
ReflectedTimes
68% confidence interval (ns)
10
1
0.1
0.01
0.001
0.001
0.01
0.1
1
10
100
Length of normal vector

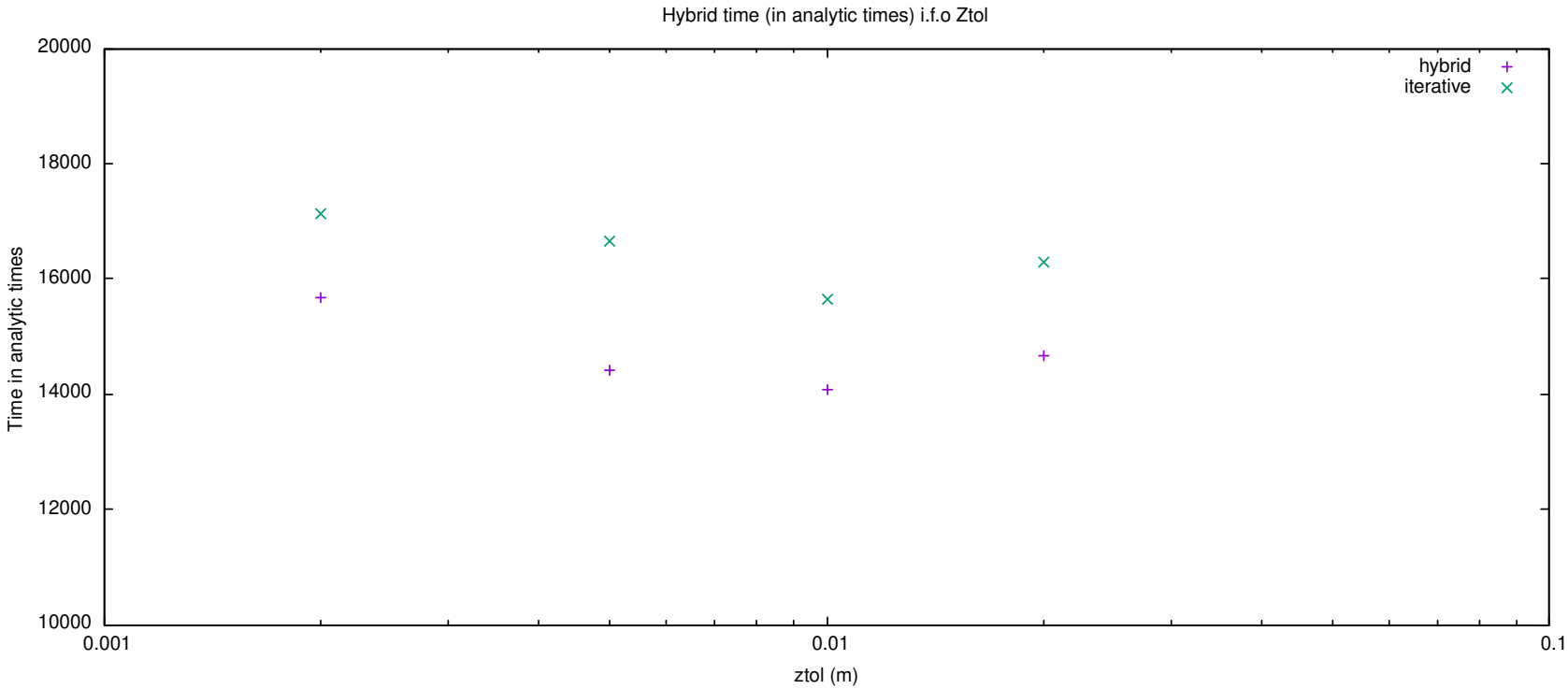

hybrid time relative to iterative time
3
2.5
2
1.5
1
0.5
0.0001
0.001
0.01
0.1
1
10
100
Length of normal vector

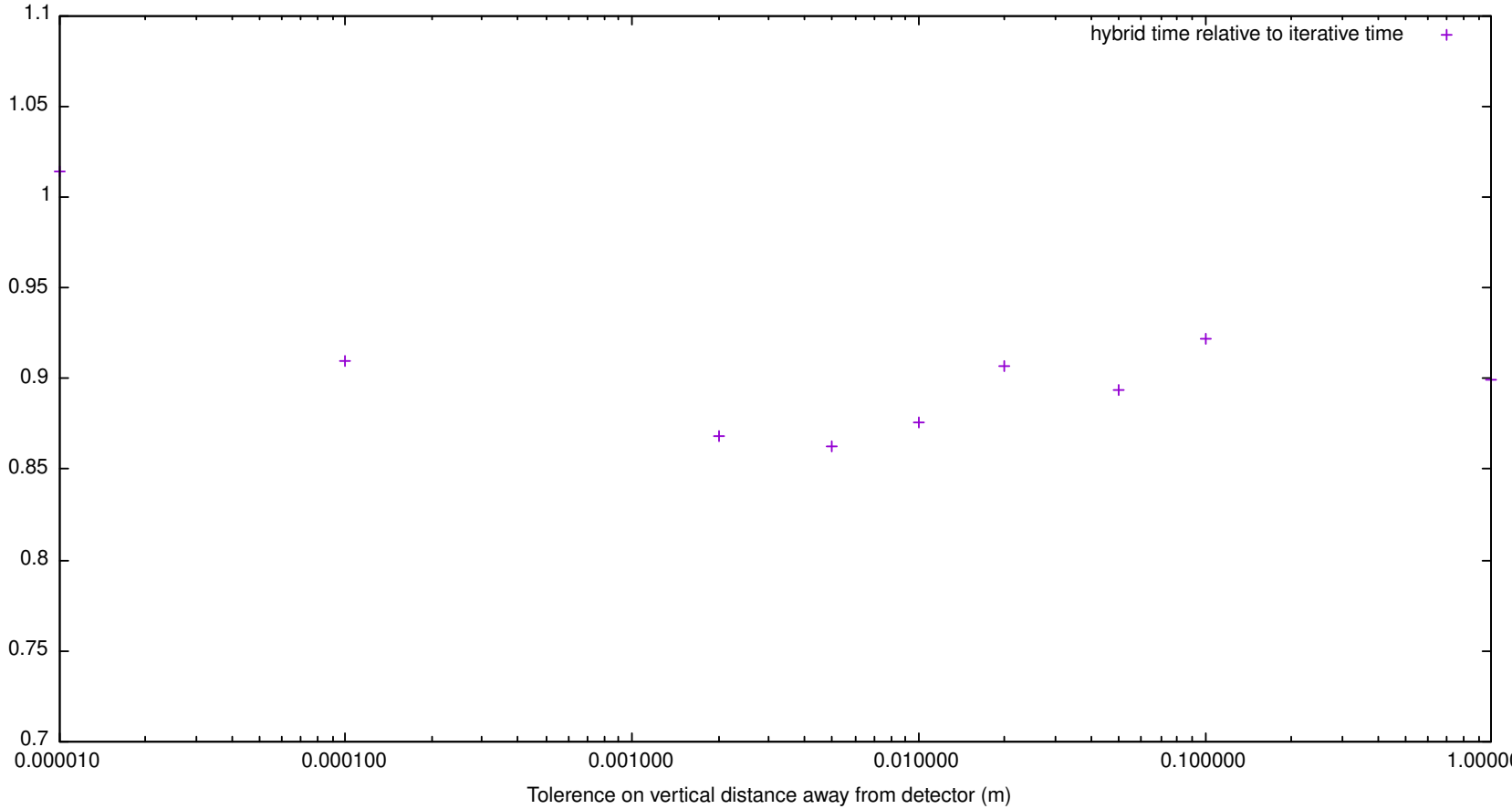

ReflectedArrivalZenith
RefractedArrivalZenith
DirectArrivalZenith
68% confidence interval (mDeg)
100
10
1
0.1
0.00010
0.00100
0.01000
0.10000
1.00000
10.00000
100.00000
Length of normal vector

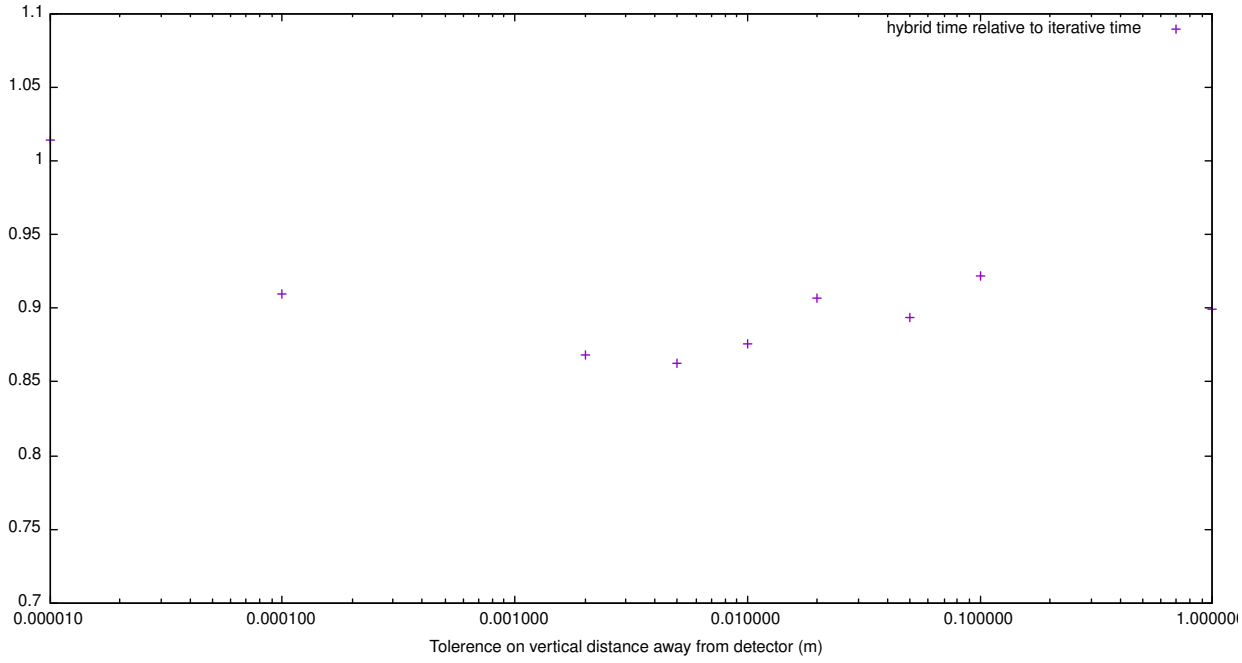

hybrid time relative to iterative time
1
0.98
0.96
0.94
0.92
0.9
0.88
0.86
0.84
0.82
0.8
0.1
1
10
Length of normal vector

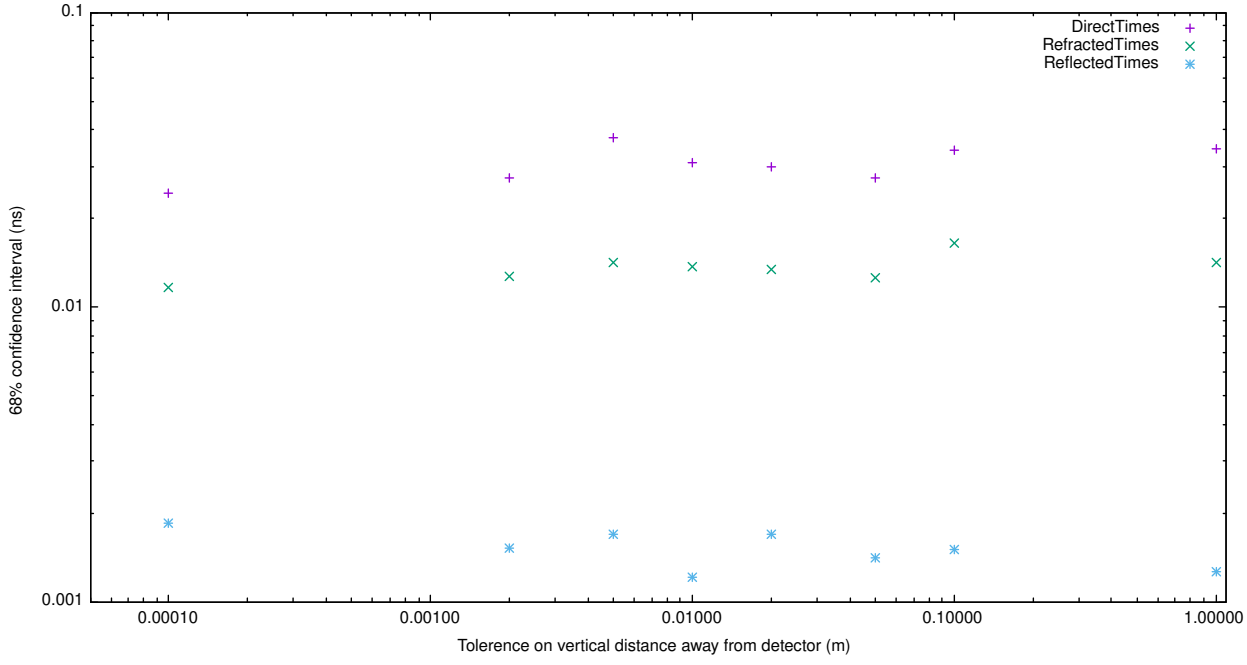
First optimization conclusion:
Take the normal vector length to be 1 meter.

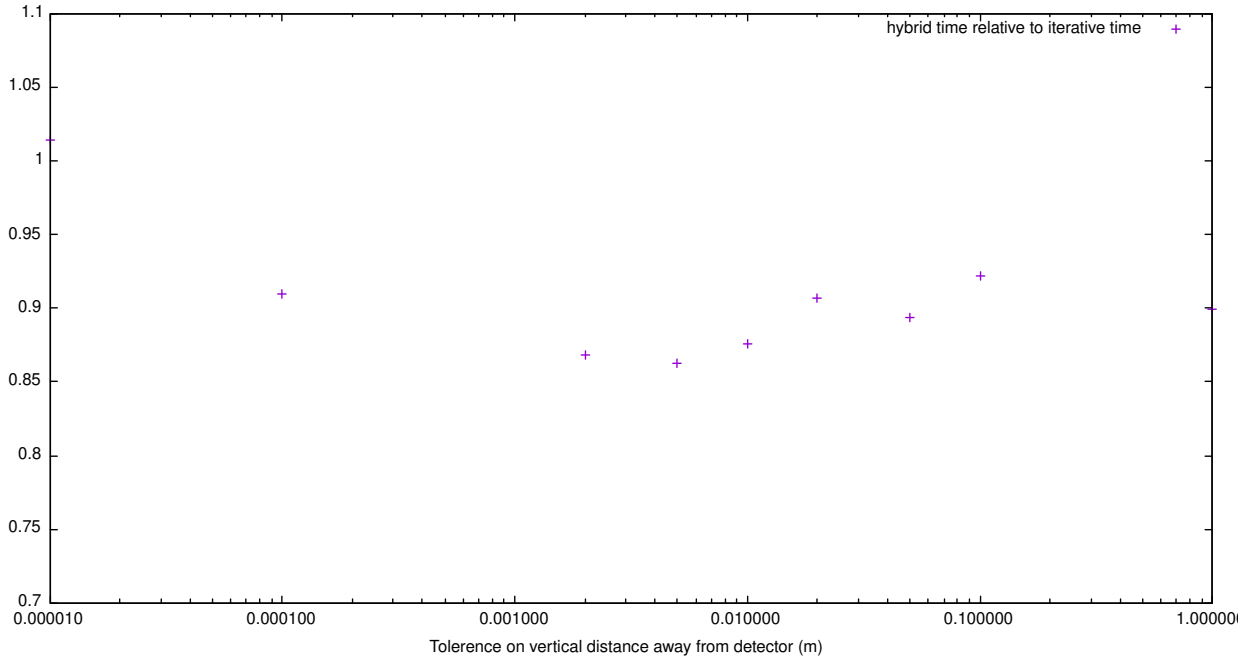

n
ΔZ

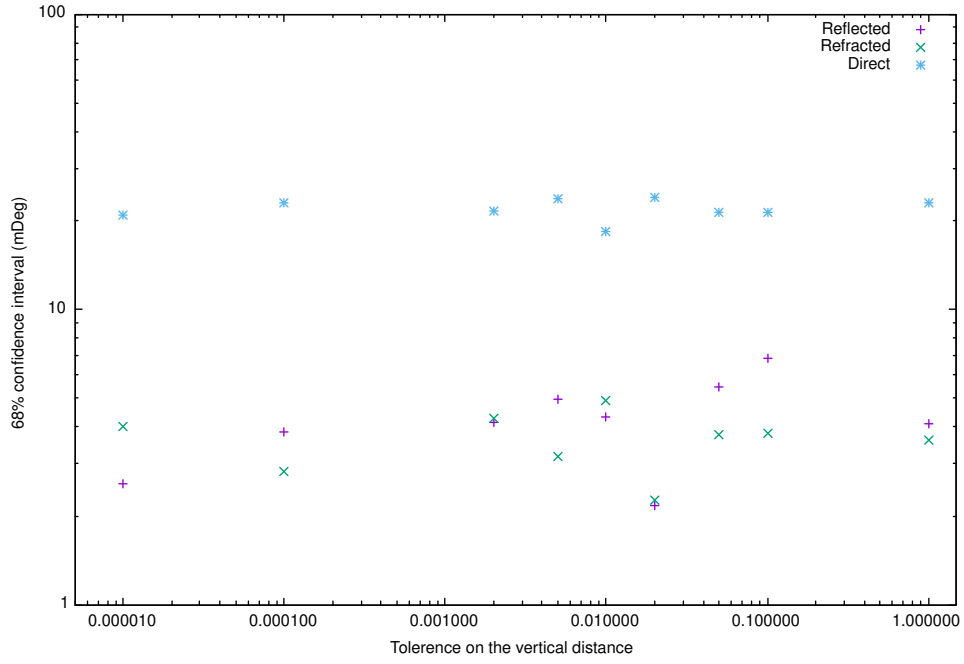

Hybrid time (in analytic times) i.f.o Ztol
Time in analytic times
ztol (m)
hybrid
iterative
20000
18000
16000
14000
12000
10000
0.001
0.01
0.1


hybrid time relative to iterative time
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0.000010
0.000100
0.001000
0.010000
0.100000
Tolerence on vertical distance away from detector (m)


hybrid time relative to iterative time
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0.000010
0.000100
0.001000
0.010000
0.100000
1.000000
Tolerence on vertical distance away from detector (m)

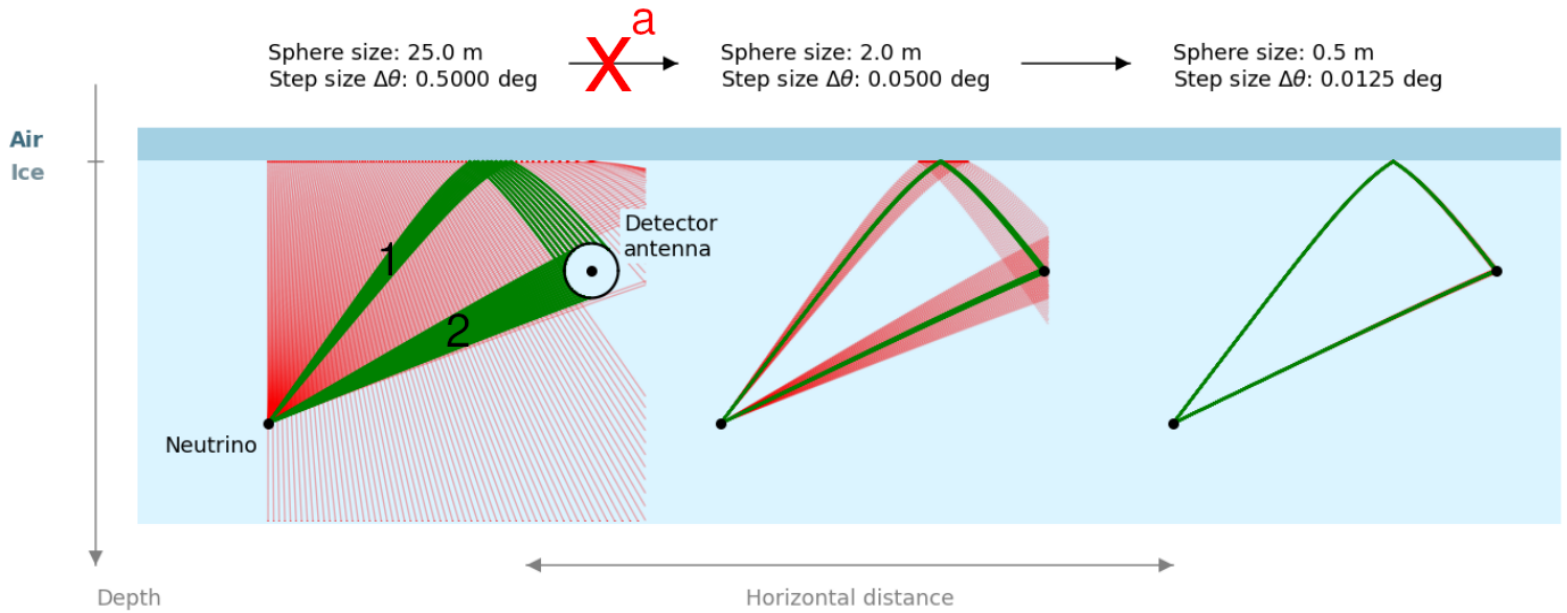

DirectTimes
RefractedTimes
ReflectedTimes
0.1
0.01
0.001
68% confidence interval (ns)
0.00010
0.00100
0.01000
0.10000
1.00000
Tolerence on vertical distance away from detector (m)


hybrid time relative to iterative time
1.1
1.05
1
0.95
0.9
0.85
0.8
0.75
0.7
0.000010
0.000100
0.001000
0.010000
0.100000
1.000000
Tolerence on vertical distance away from detector (m)


Reflected
Refracted
Direct
100
10
1
68% confidence interval (mDeg)
0.000010
0.000100
0.001000
0.010000
0.100000
1.000000
Tolerence on the vertical distance

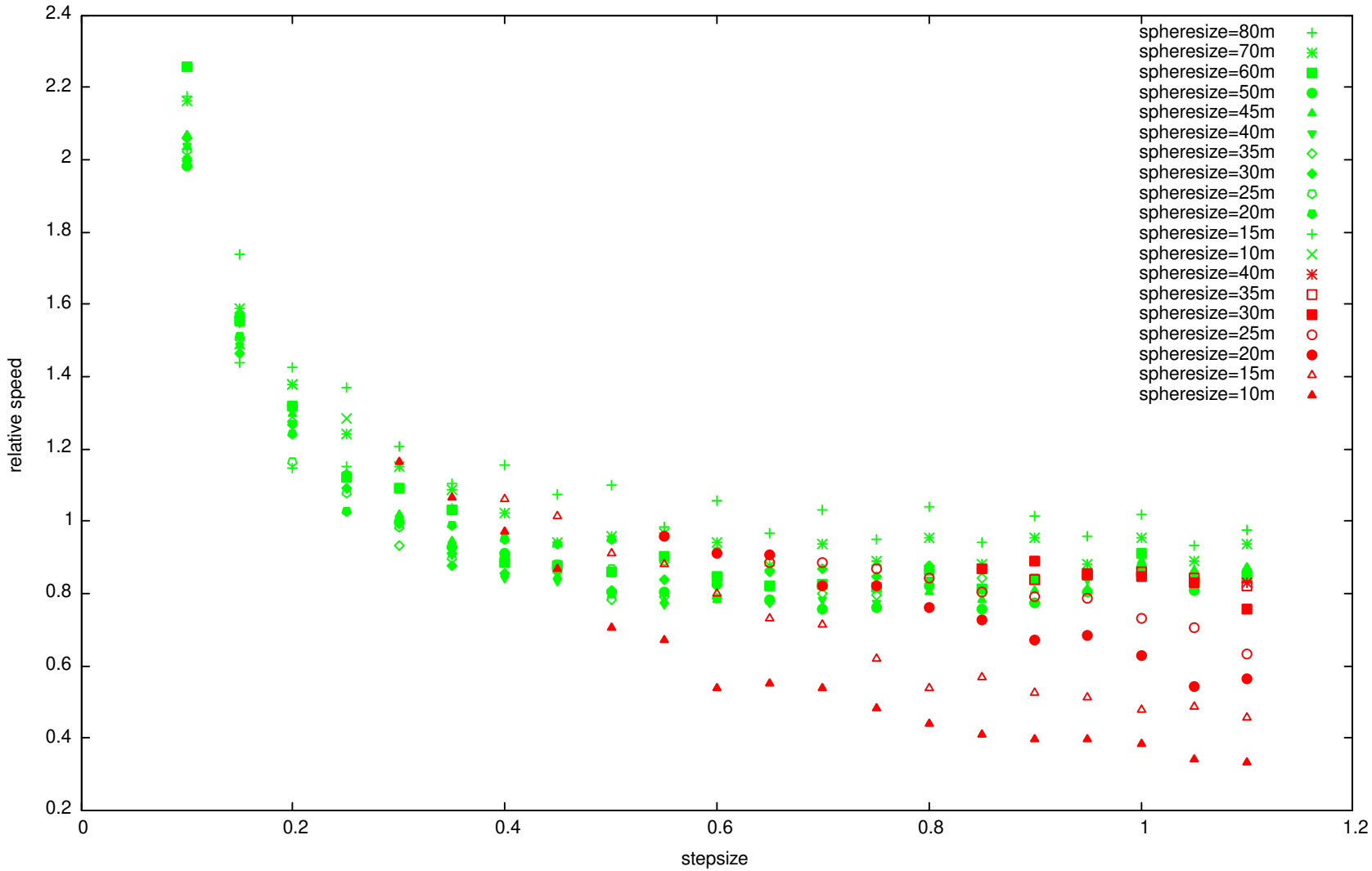
Second optimization conclusion:
Take ztol to be 0.05 m.

Sphere Size & Step Size

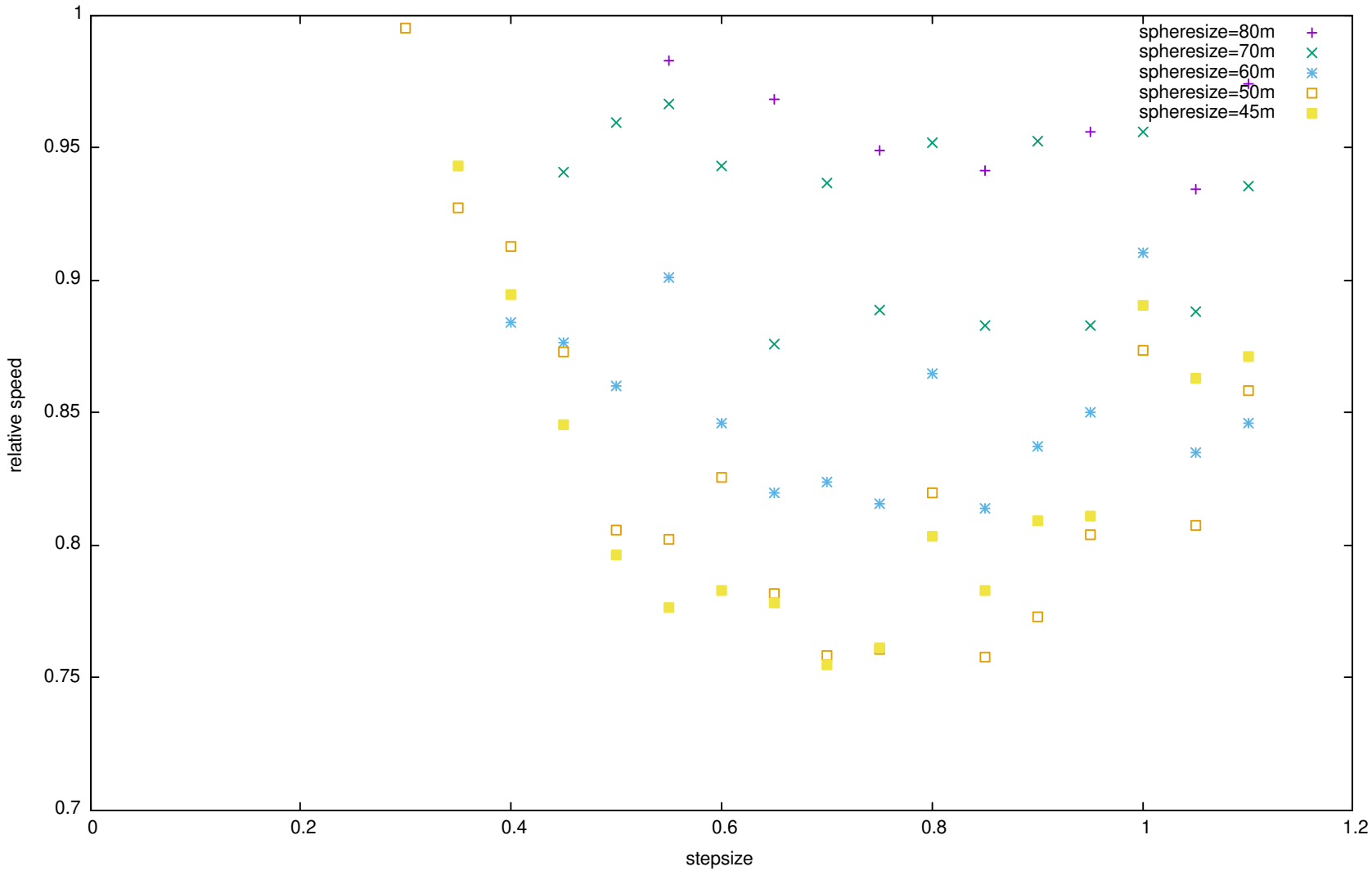


a process is broken out of as 2 distinct launch regions (region 1 & 2) are found.

Sphere Size & Step Size



Sphere Size & Step Size



Final Result

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

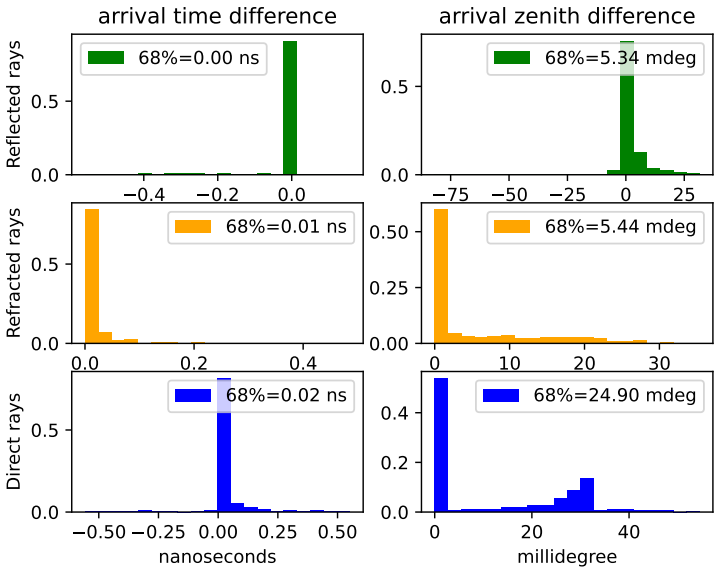


Figure: Hybrid

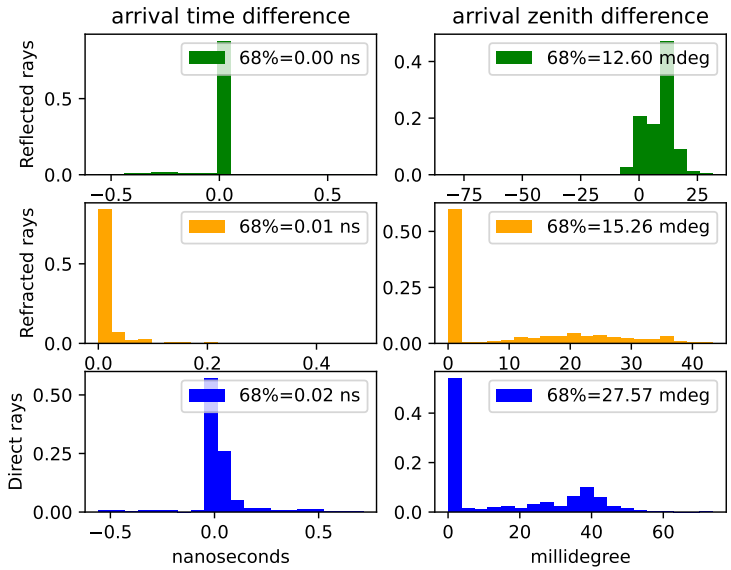


Figure: Iterative

- iterative :1.627s
- hybrid : 1.226s (32.7% faster)
- analytic: 9.719e-05 seconds

What if the same sphere and stepsize?

- iterative :1.80317s
- hybrid : 1.35776s (32.8% faster)
- analytic: 9.8812e-05 seconds

Exactly the same σ's