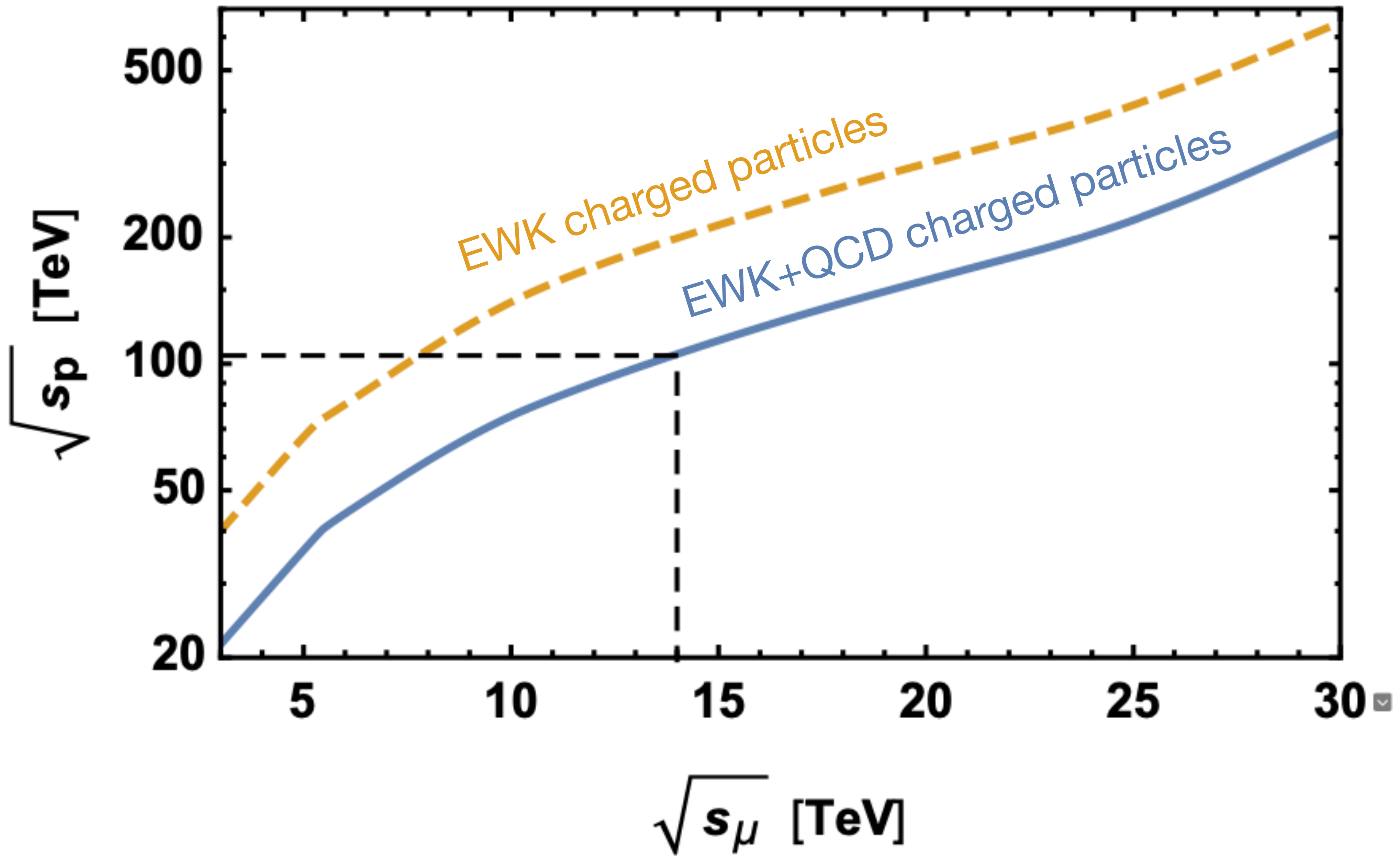
How to Limit the Beam-Induced Background in a Muon Collider

Daniel Ally

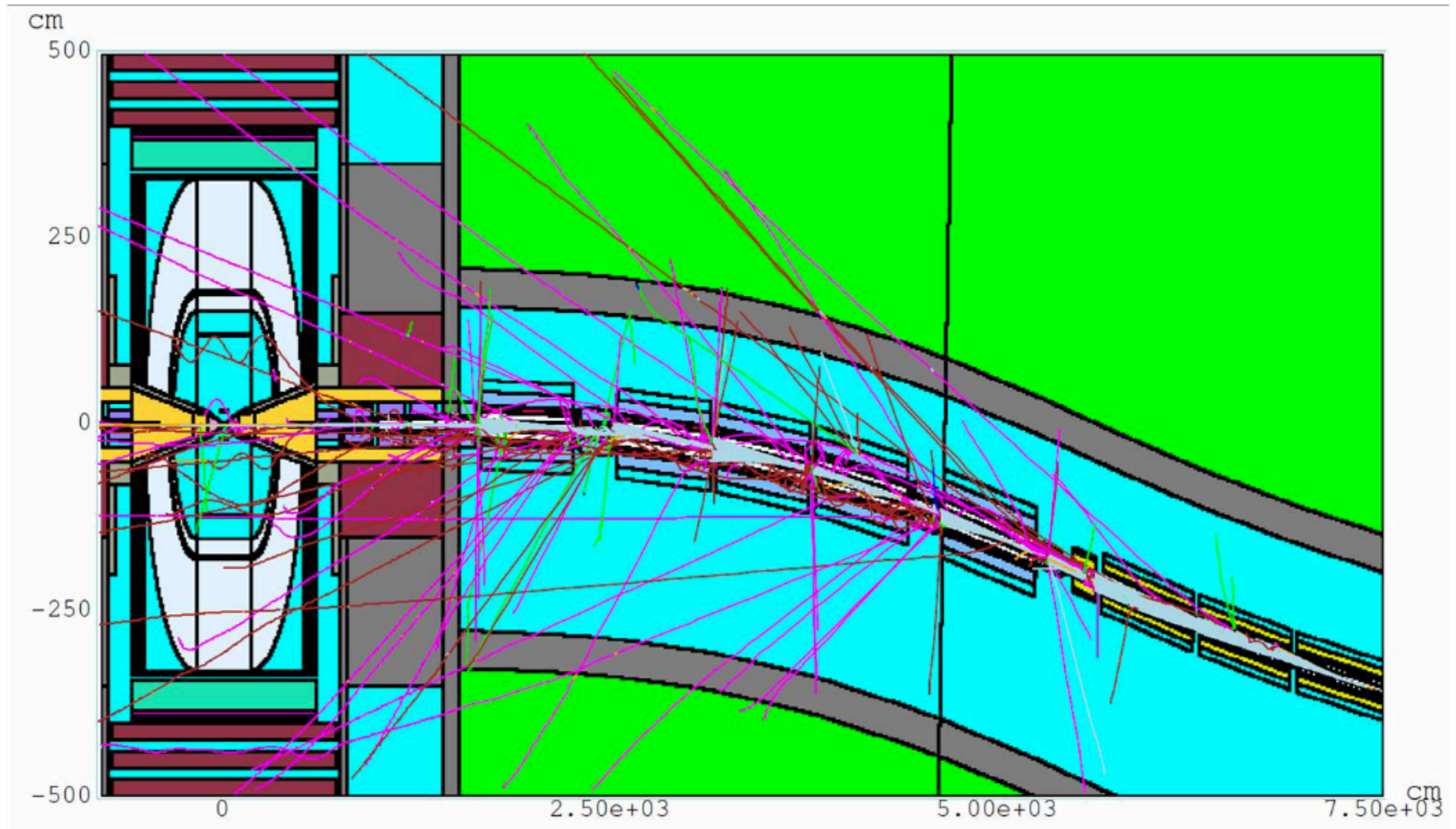
Introduction

- Muons are fundamental particles
- Muon Colliders can explore physics sectors hard to reach with the LHC
  - Increased Higgs sensitivity
  - Dark Matter
  - Beyond the Standard Model (BSM) physics



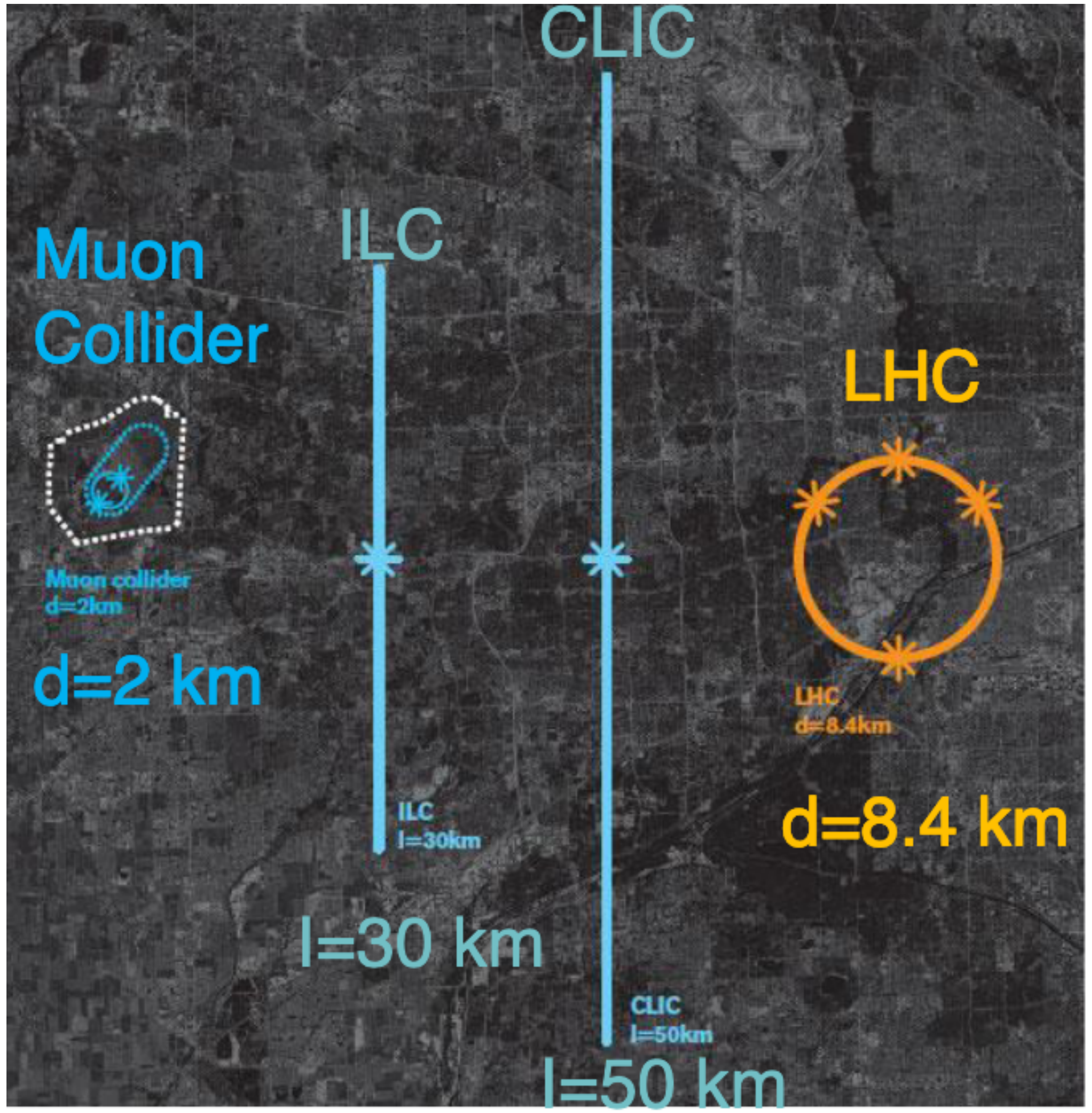
Difficulties

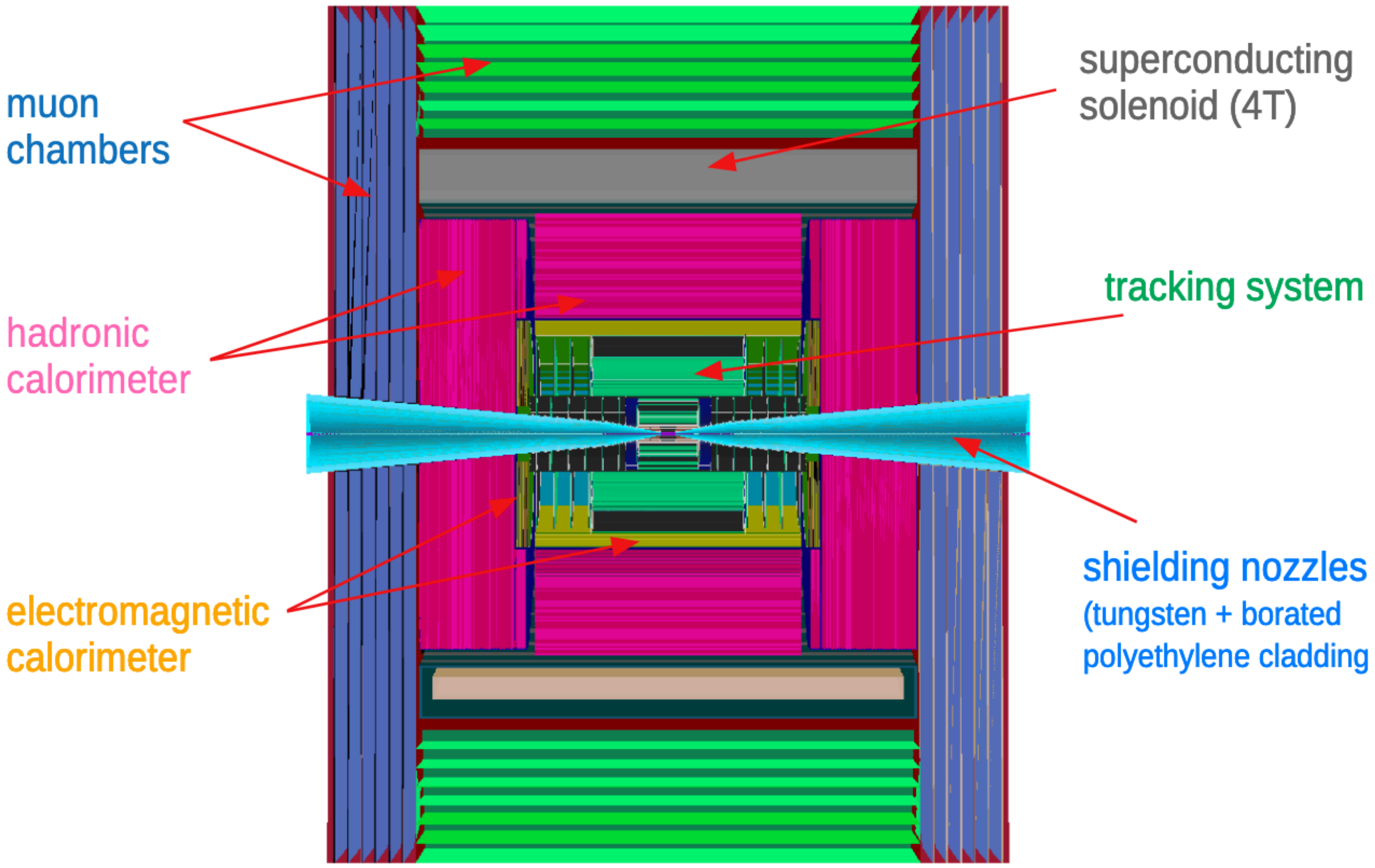
- The beam-induced background (BIB) is one of the biggest hurdles in constructing a muon collider.
- Primary source: $\mu \rightarrow e\nu\bar{\nu}$ decays
- The electrons/positrons then cause EM showers in the detector



- For scale, one BIB event, at $\sqrt{s} = 1.5$ TeV, produces ~500,000 sim hits.
- 1 hard scatter event at the same energy, produces ~200 sim hits.

Detector





Vertex Detector (VXD)
- 4 double-sensor barrel layers 25x25μm^2
- 4+4 double-sensor disks 25x25μm^2

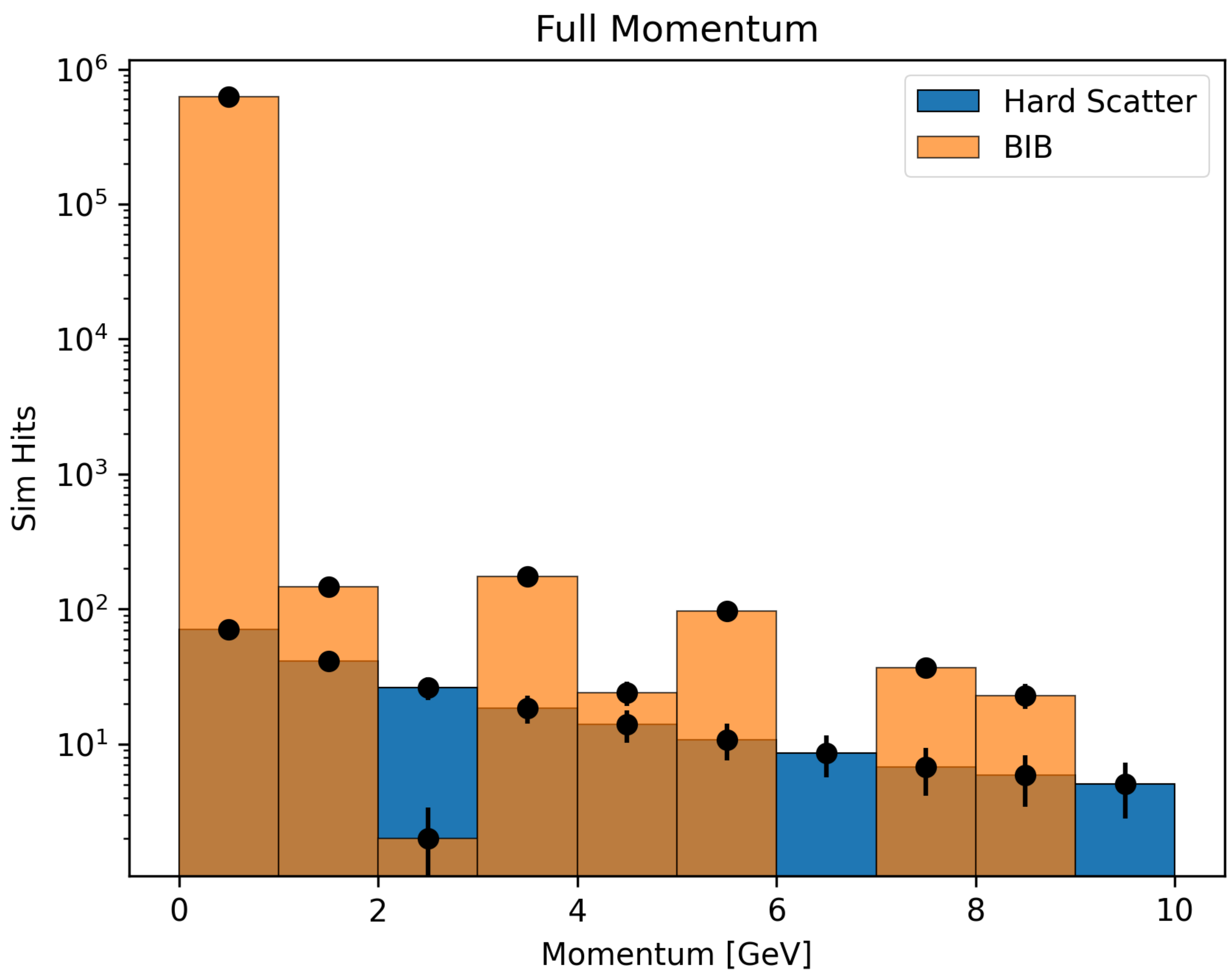
Inner Tracker (IT)
- 3 barrel layers 50x50μm^2
- 7+7 disks ”

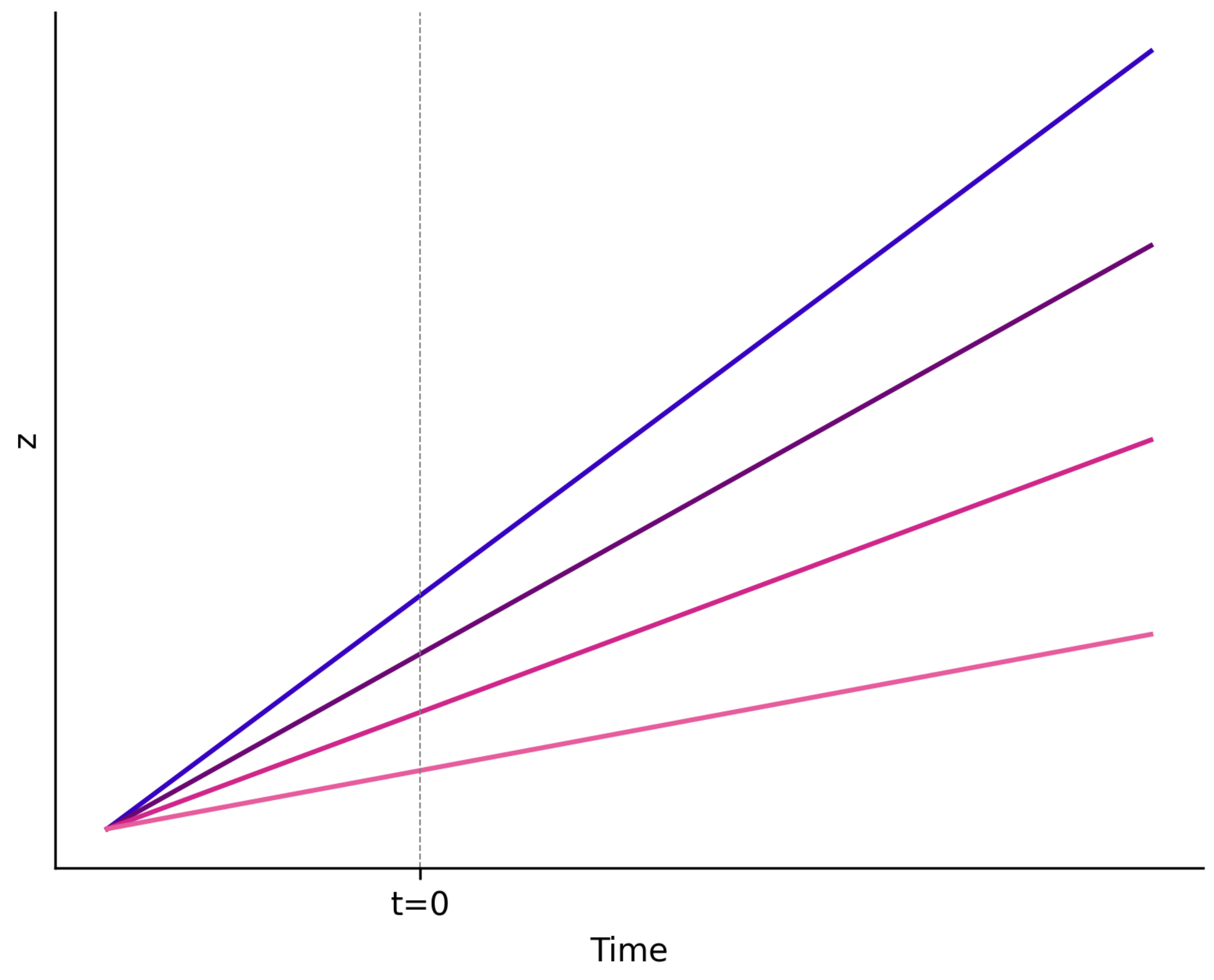
Outer Tracker(OT)
- 3 barrel layers 50x50μm^2
- 4+4 disks ”

Electromagnetic Calorimeter (ECAL)
- 40 layers W absorber and silicon pad sensors, 5x5 mm^2

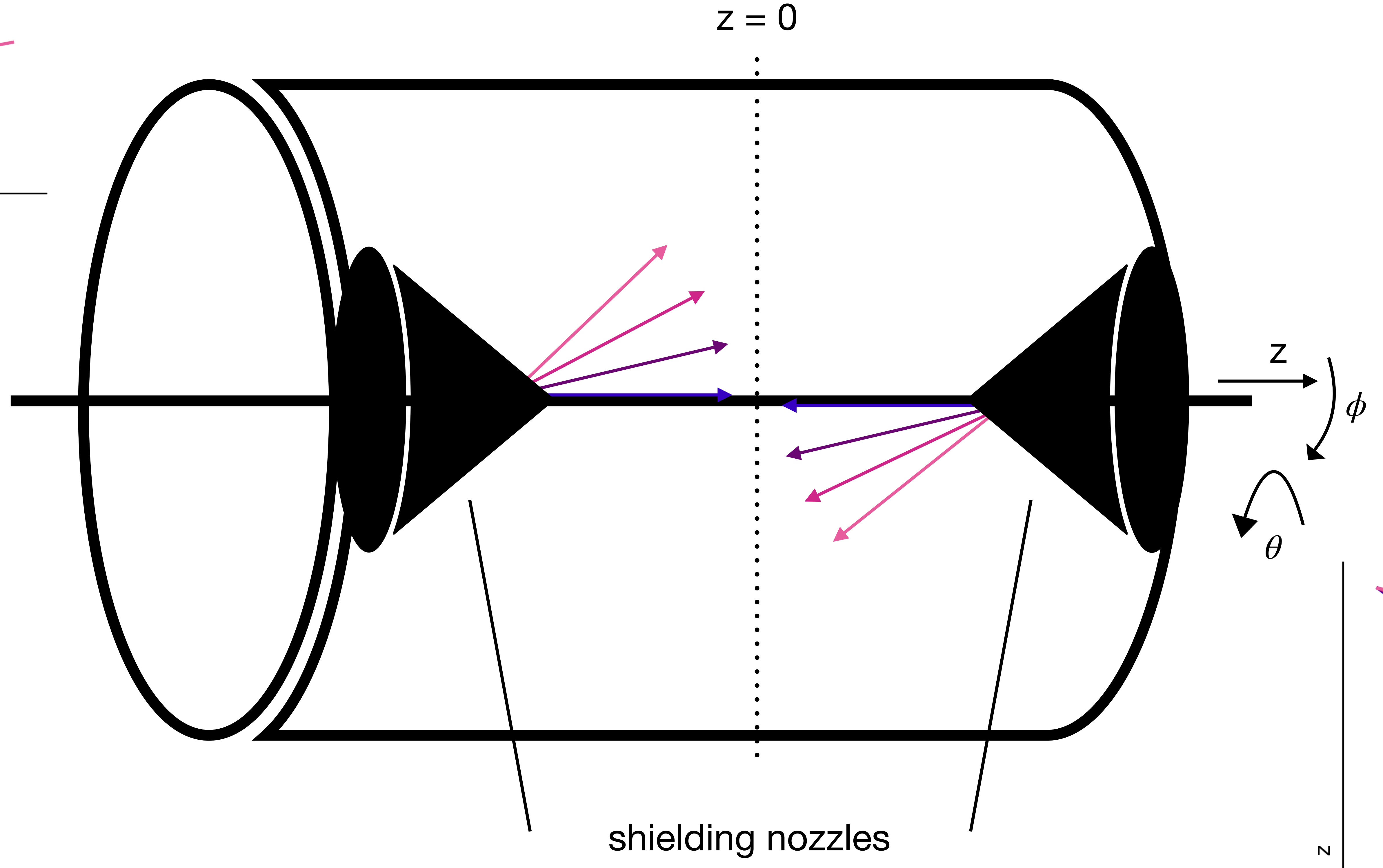
Hadron Calorimeter (HCAL)
- 60 layers steel absorber & plastic scintillating tiles, 30x30 mm^2

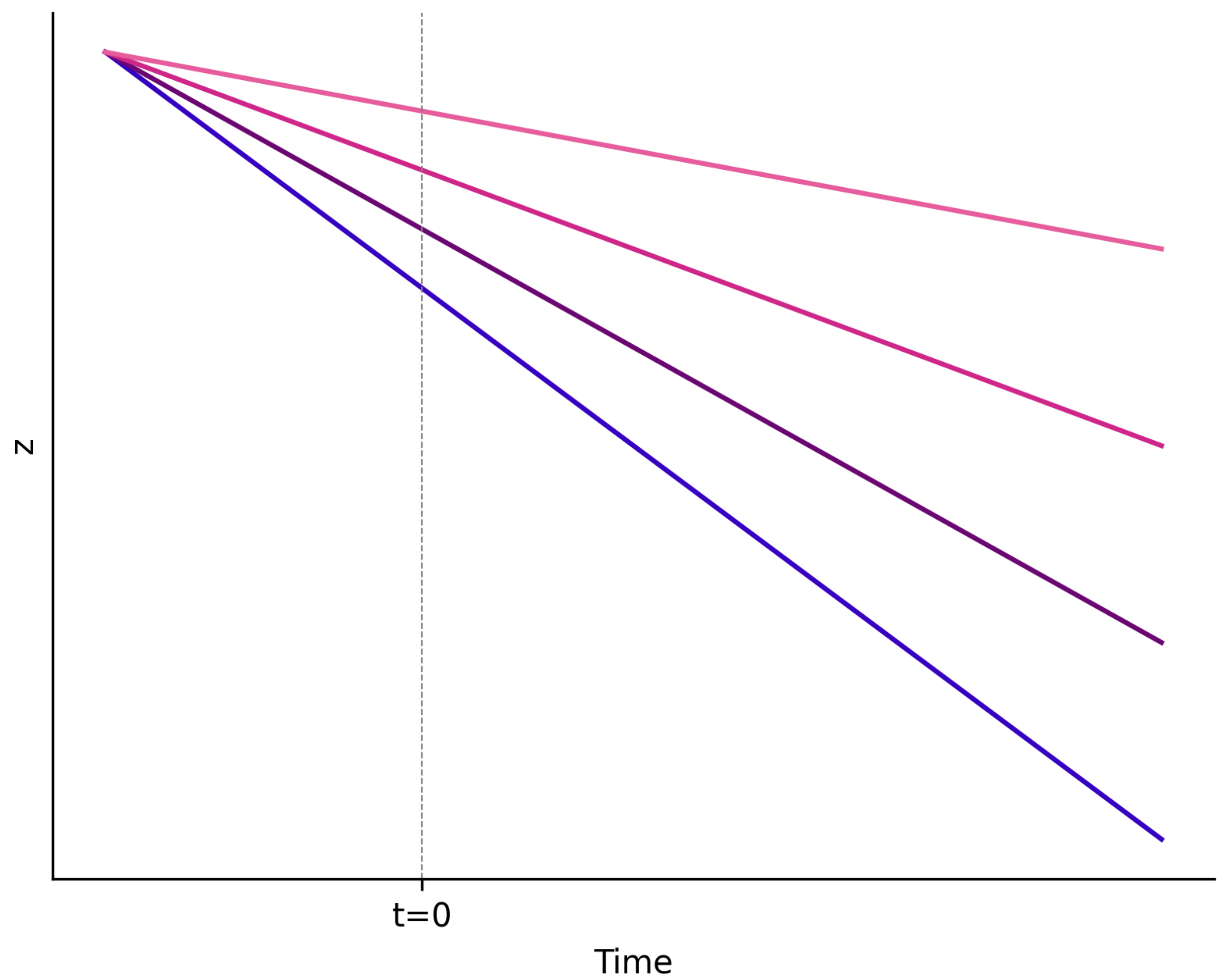
- Hard scatter is made up of:
  - mu+ mu- > z h h
  - mu+ mu- > vm vm~ h h
  - mu+ mu- > mu+ mu- h h
- Our goal is to cut BIB but not signal
  - We define signal as hard scatter hits with momentum > 1 GeV
- Hits are not trackable at this level in analysis
- We don’t consider 27.4% of the sim hits from the hard scatter signal



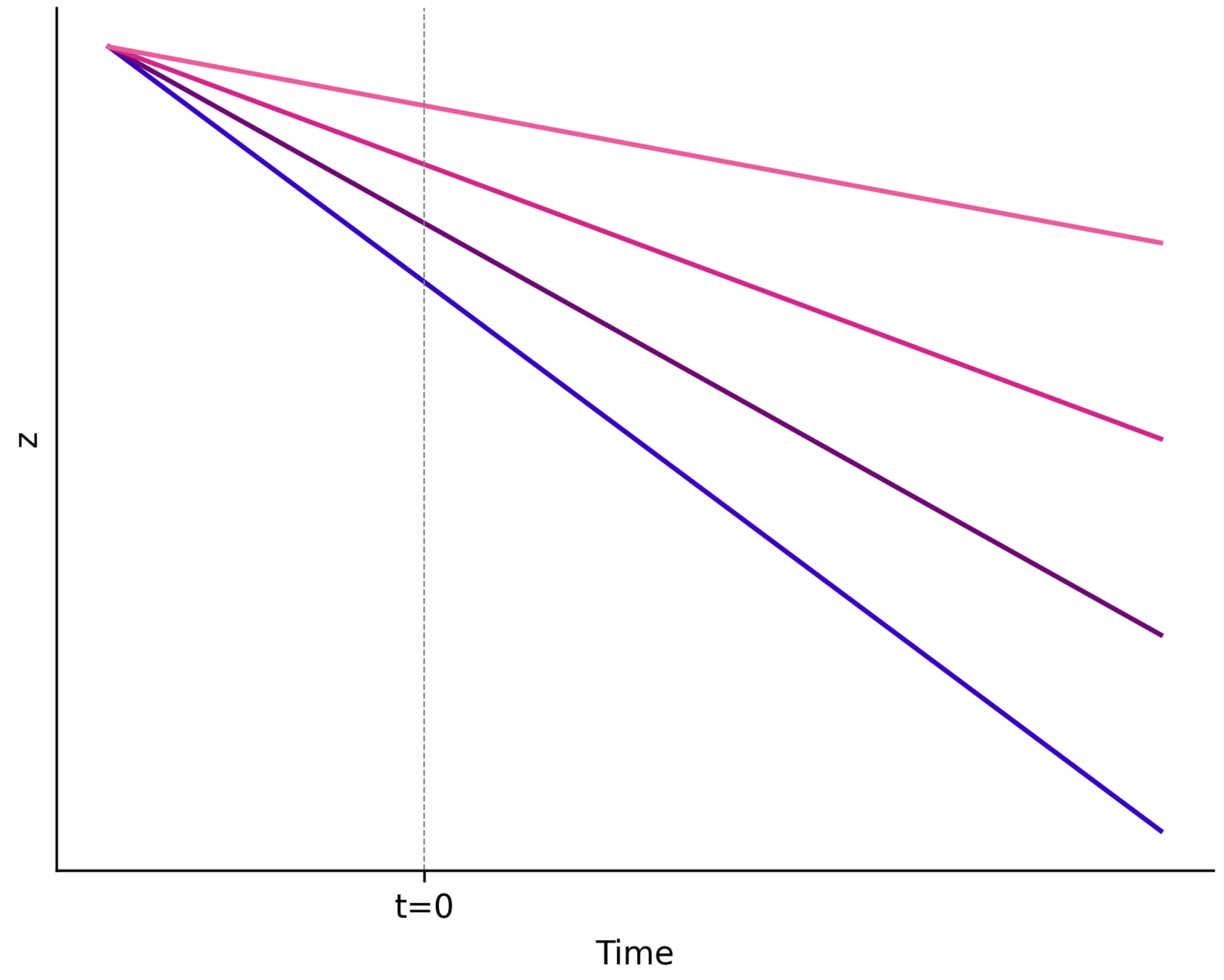


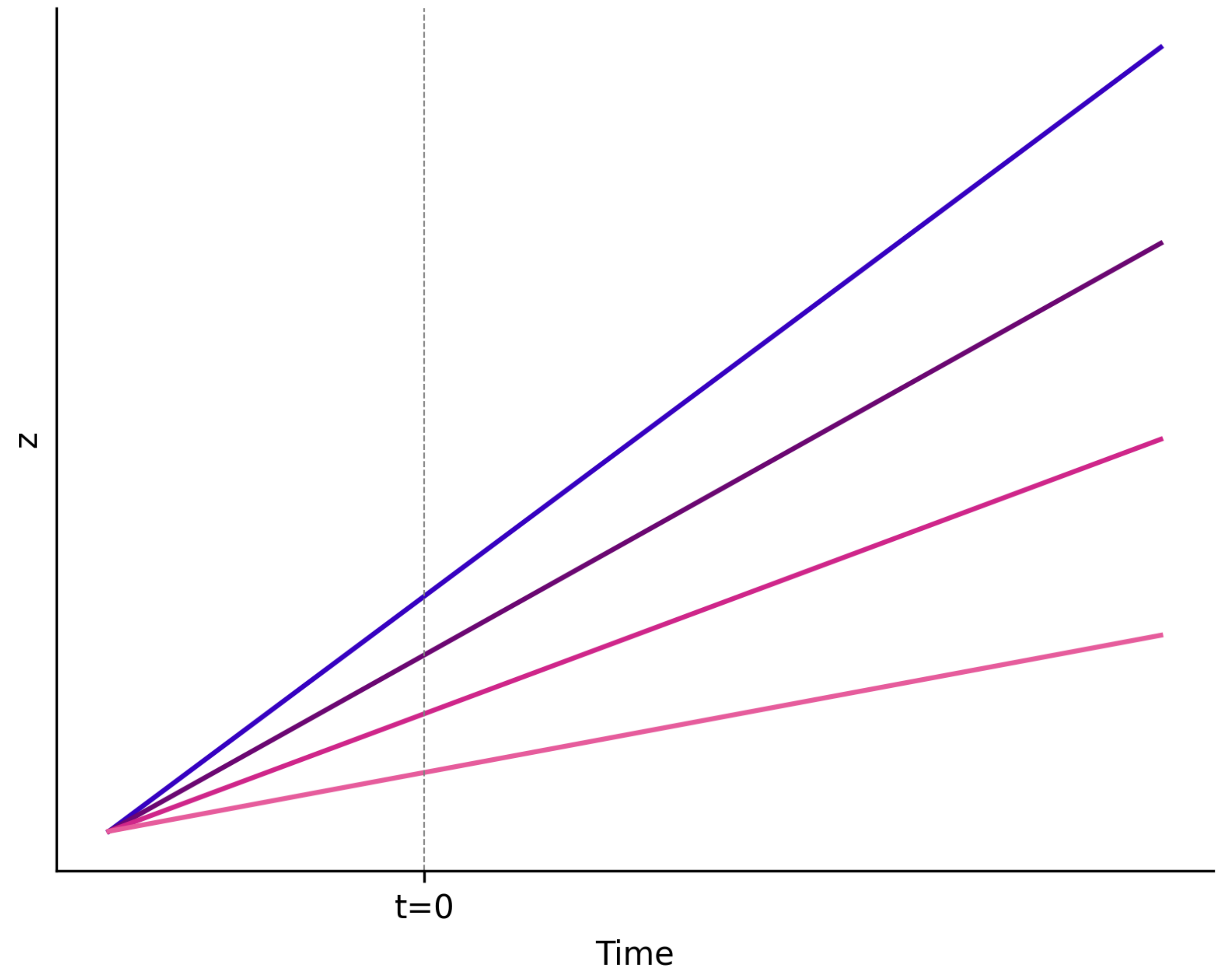
BIB

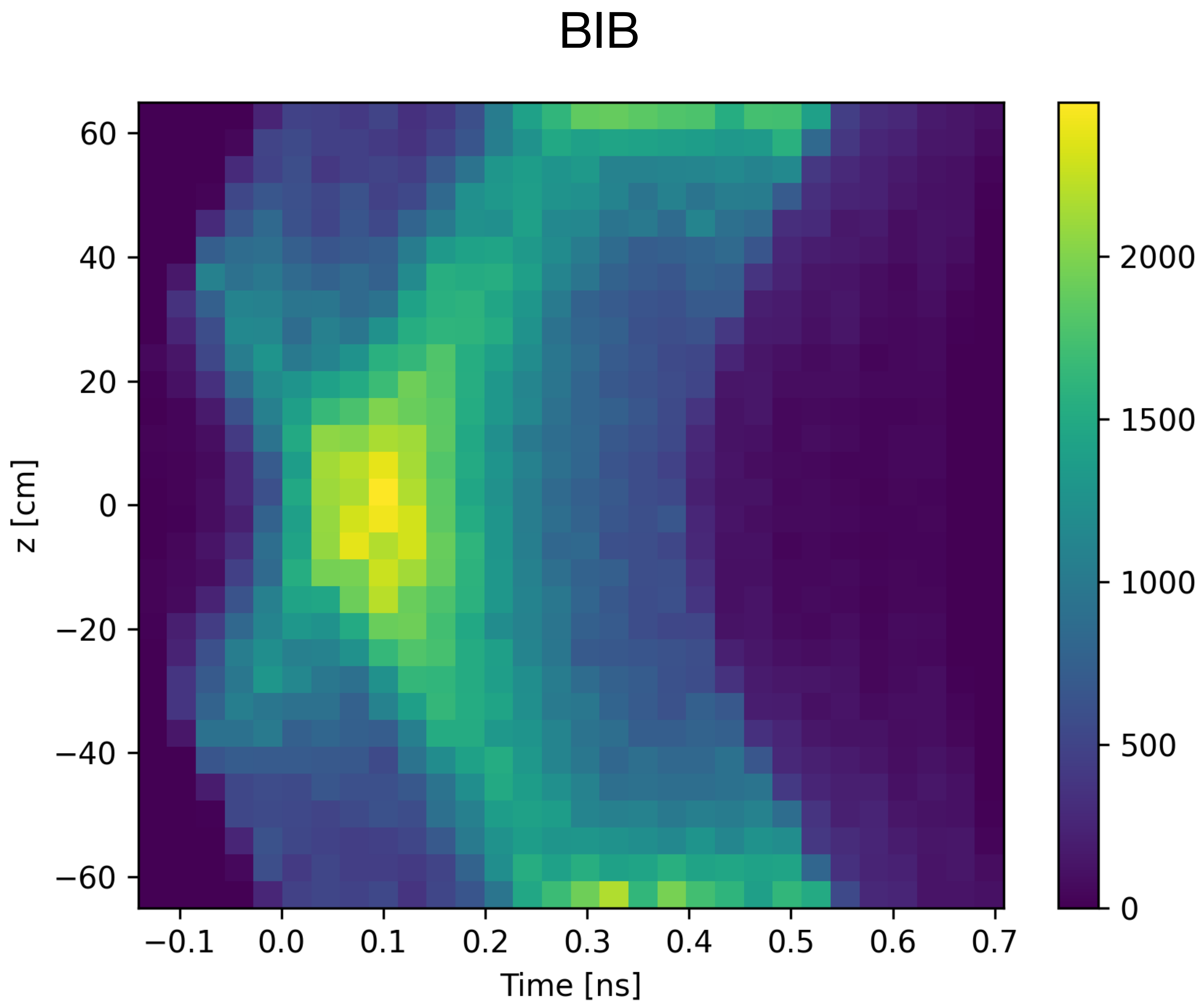




What we see

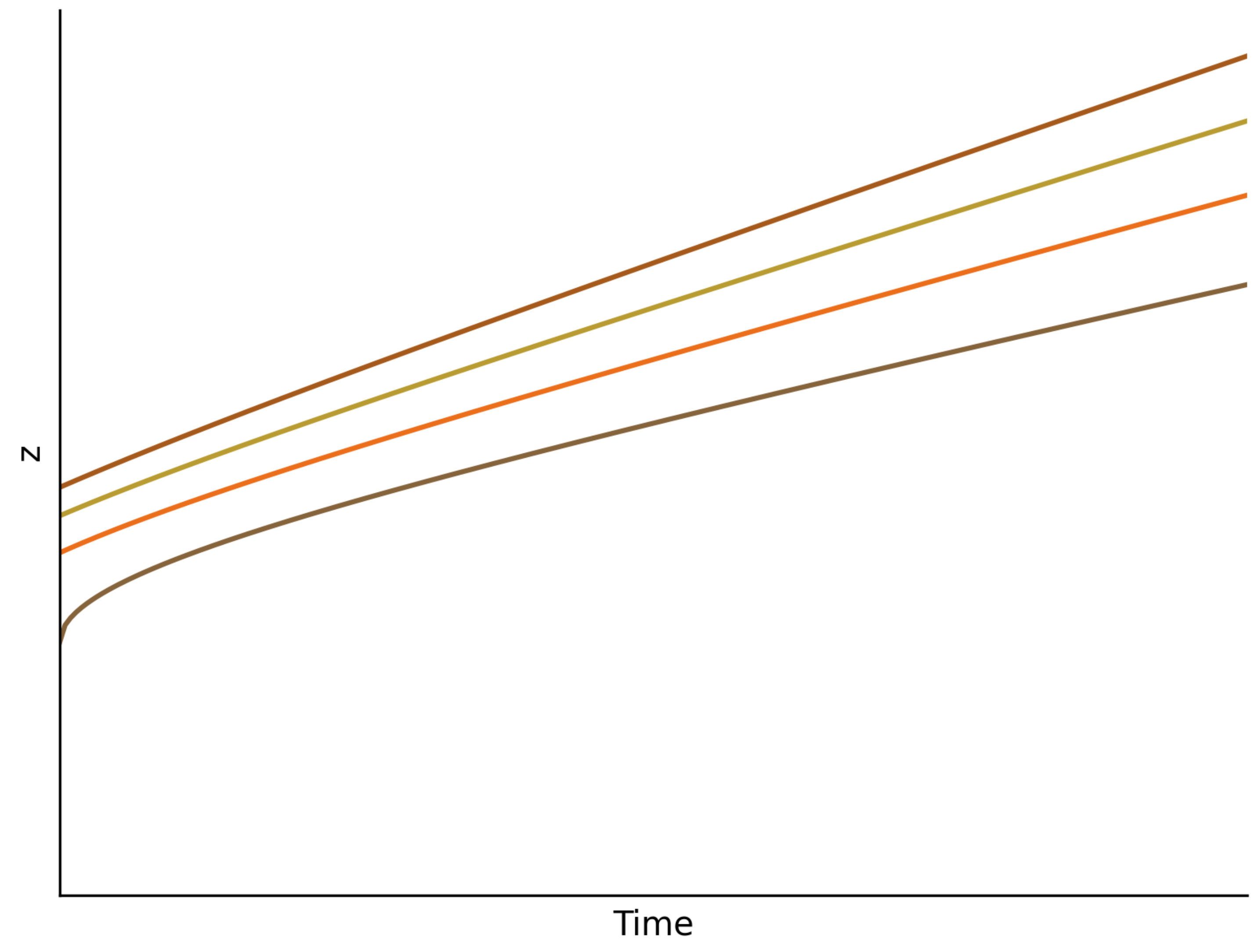

z
t=0
Time


z
t=0
Time

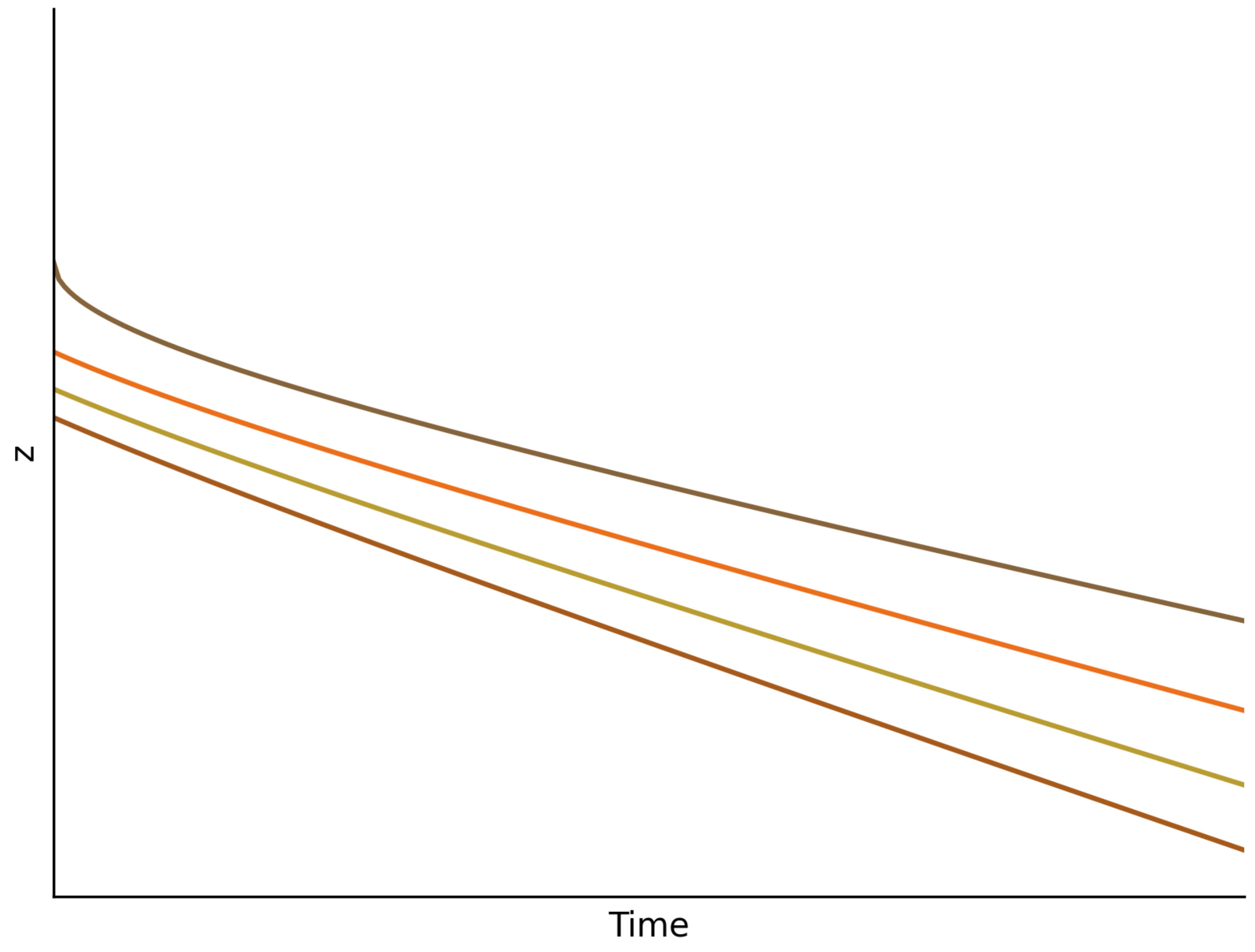

BIB
z [cm]
60
40
20
0
−20
−40
−60
−0.1
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Time [ns]
2000
1500
1000
500
0


z
Time
z = 0
z
ϕ
θ
shielding nozzles
z
Time

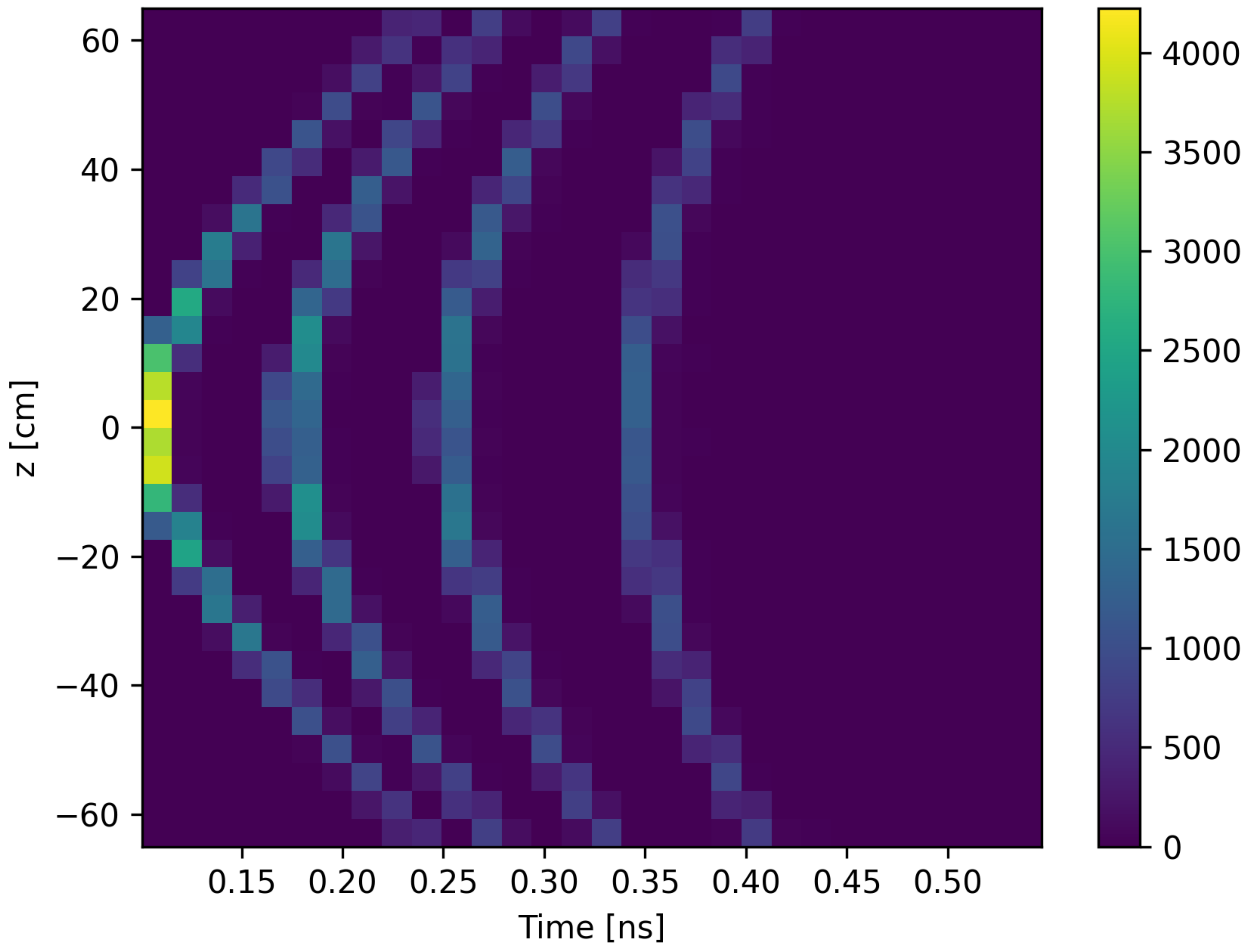
What we see



z
Time

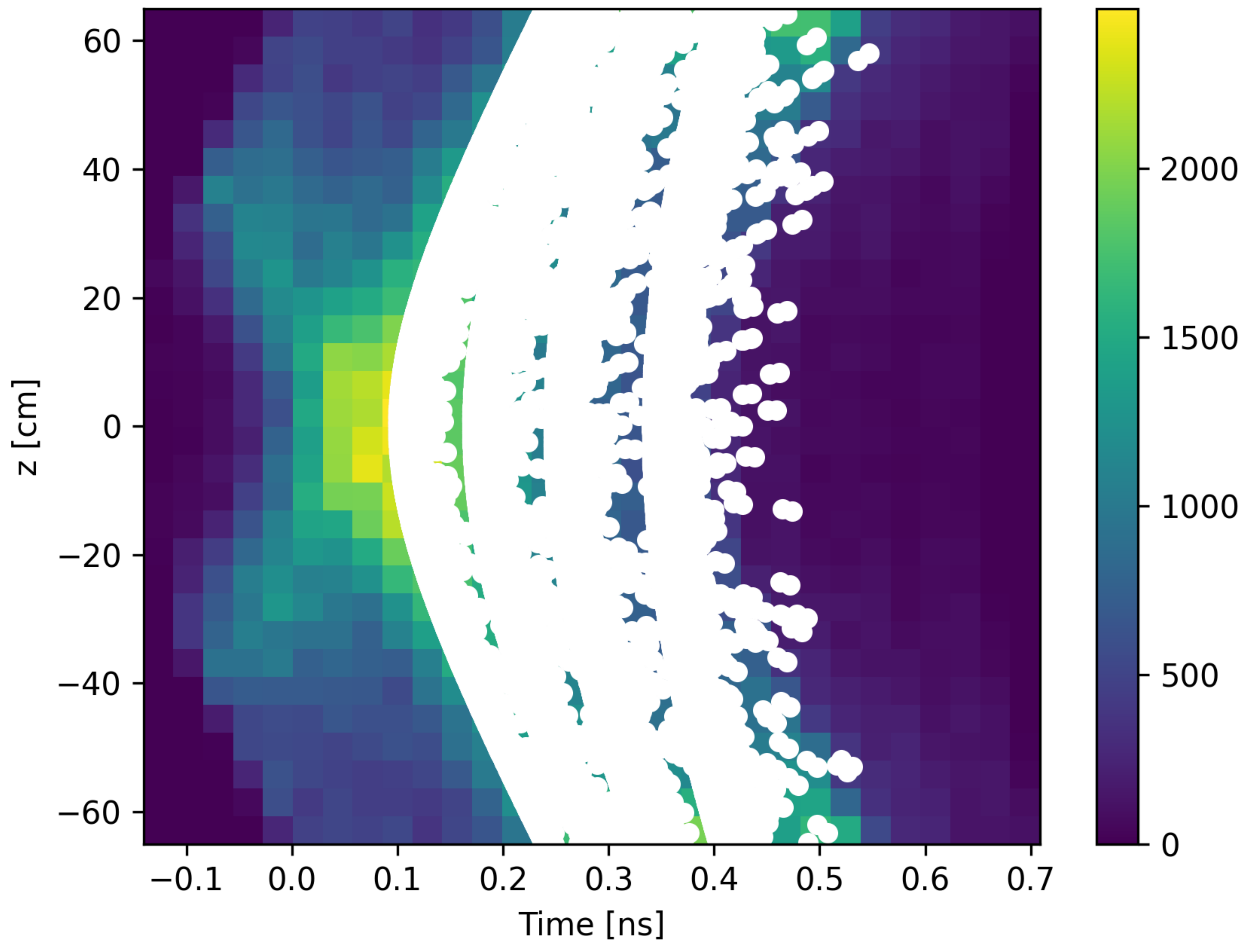


z
Time



60
40
20
0
−20
−40
−60
z [cm]
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
Time [ns]
4000
3500
3000
2500
2000
1500
1000
500
0

Time Distribution



- Since there is a pattern to the hard scatter, let's see if there's a cut.
- The inspiration for checking for a time cut comes from Larry's slides on <u>Sim Hit Timing</u>

White circles represent collision particle Sim Hits

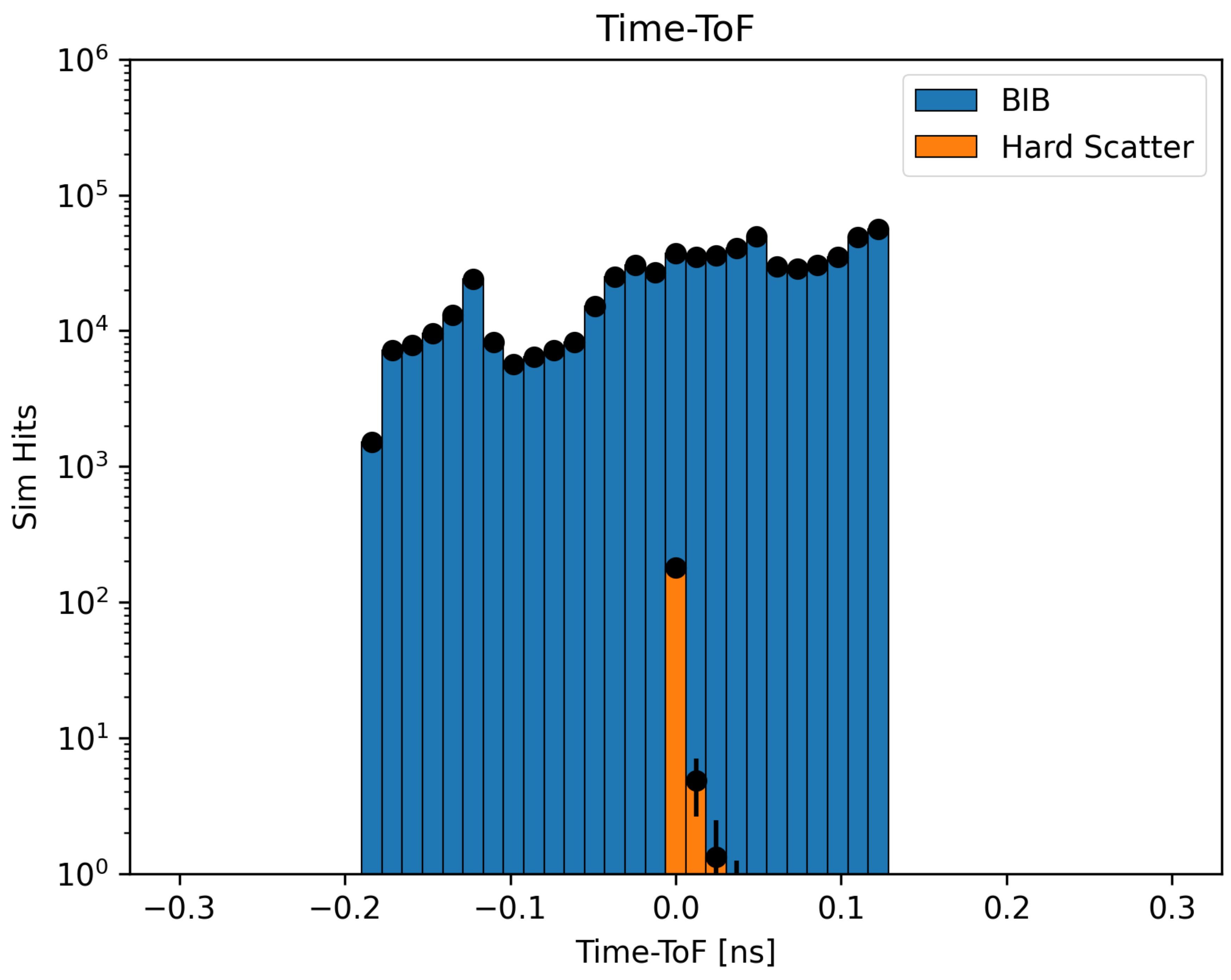
Time Cut

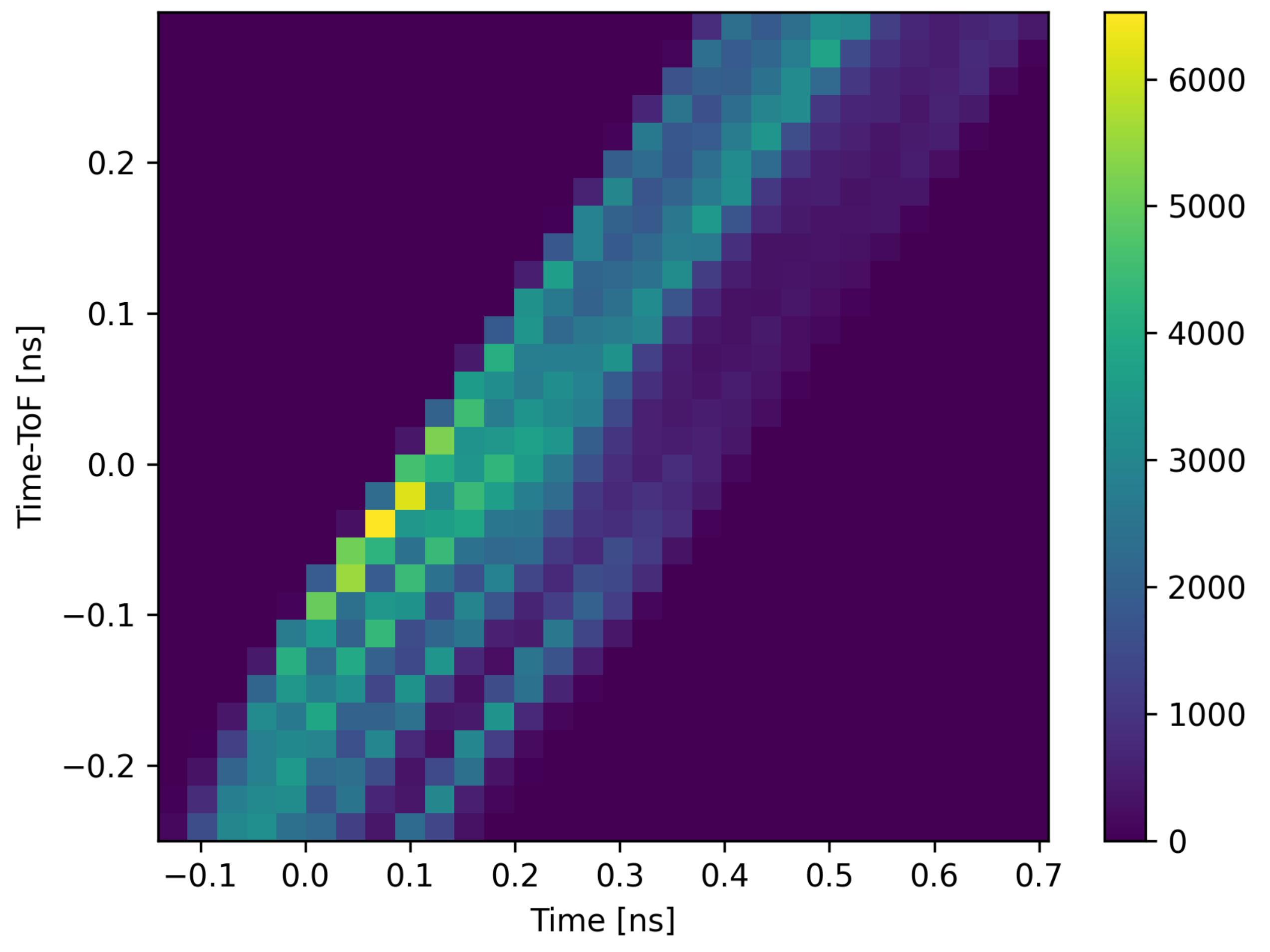
- Larry notes that the signal is localized around zero and first makes a cut
- We assume the cut is for

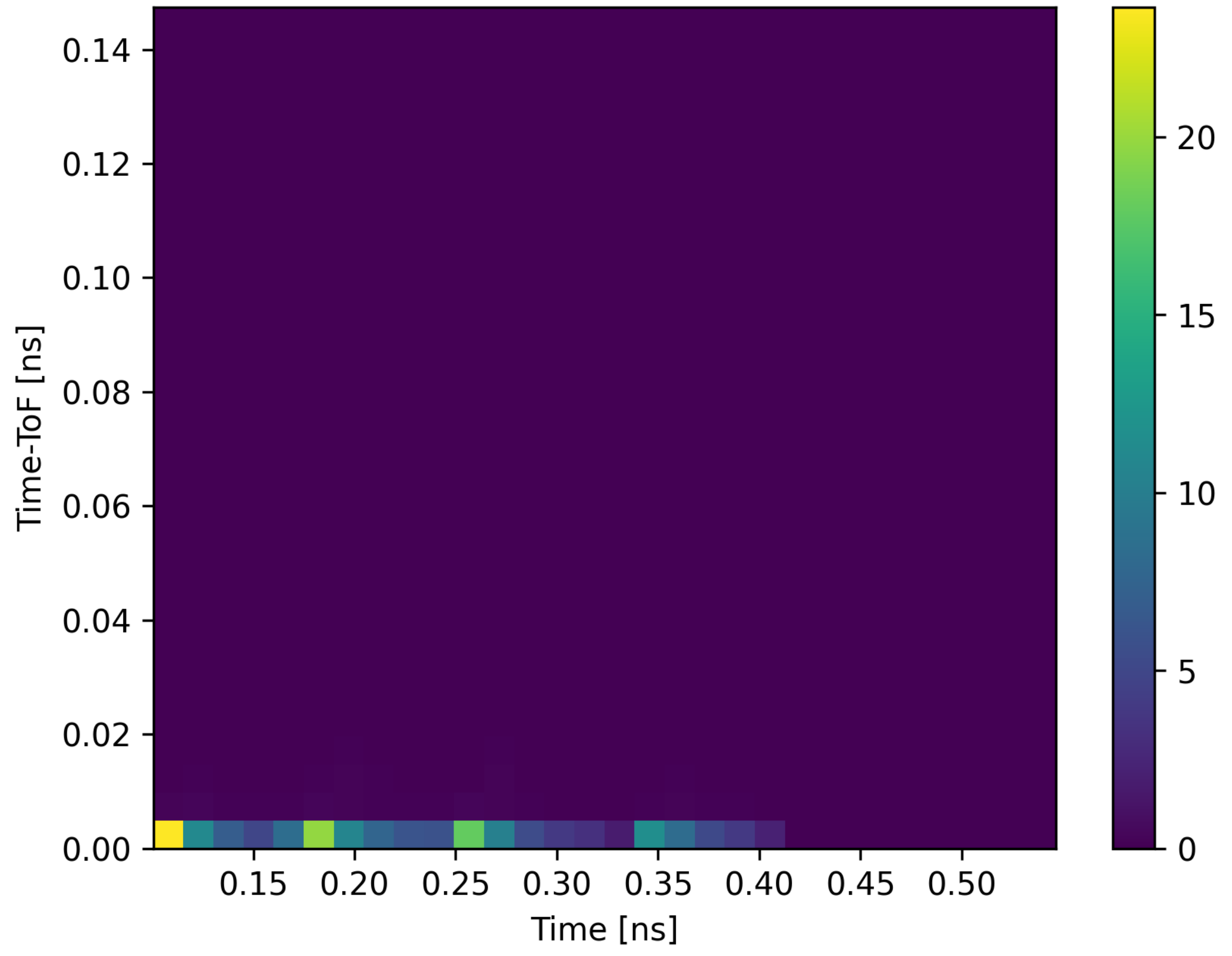
$$|\mathrm{T} - \mathrm{ToF}| < 20\,ps$$

- We define time as how long after the collision a particle reaches the detector
- We define time of flight (ToF) as the time it would take a particle that originated at the collision point to travel its recorded distance if traveling at c.

$$\mathrm{ToF} = \frac{\sqrt{z^2 + R^2}}{c}$$





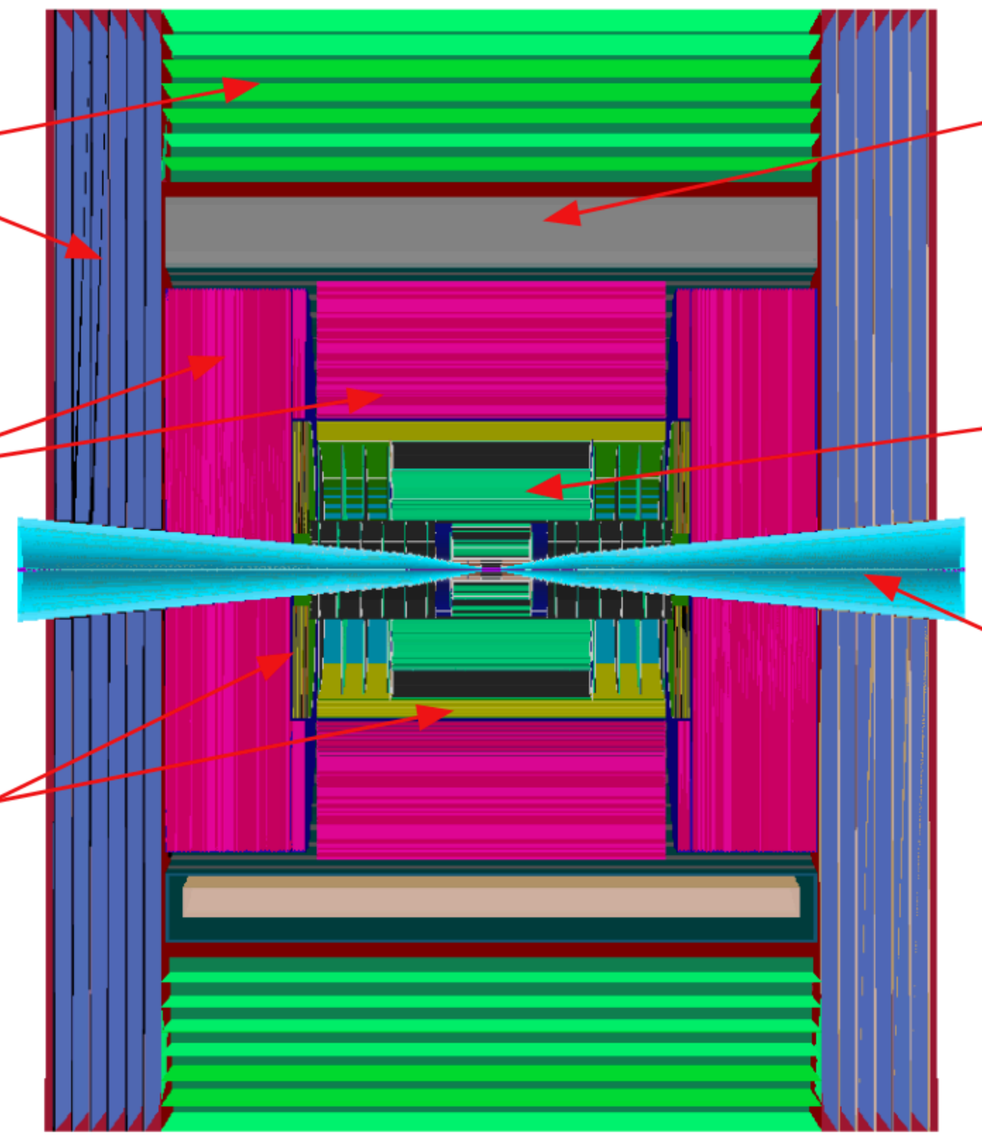


$\|T\text{-}ToF\|$	Background	Signal
10 ps	95.3%	2.60%
20 ps	90.7%	1.17%
30 ps	86.2%	0.618%
50 ps	77.6%	0.234%
100 ps	57.8%	0.030%
200 ps	23.8%	0.00%

- We don’t know the timing resolution of the detector.
- Here is a chart of the percentage of hits cut if we increase the time difference
- We include the 20 ps cut going forward

Geometry

- One way we might want to limit the BIB, is by using a different detector geometry.



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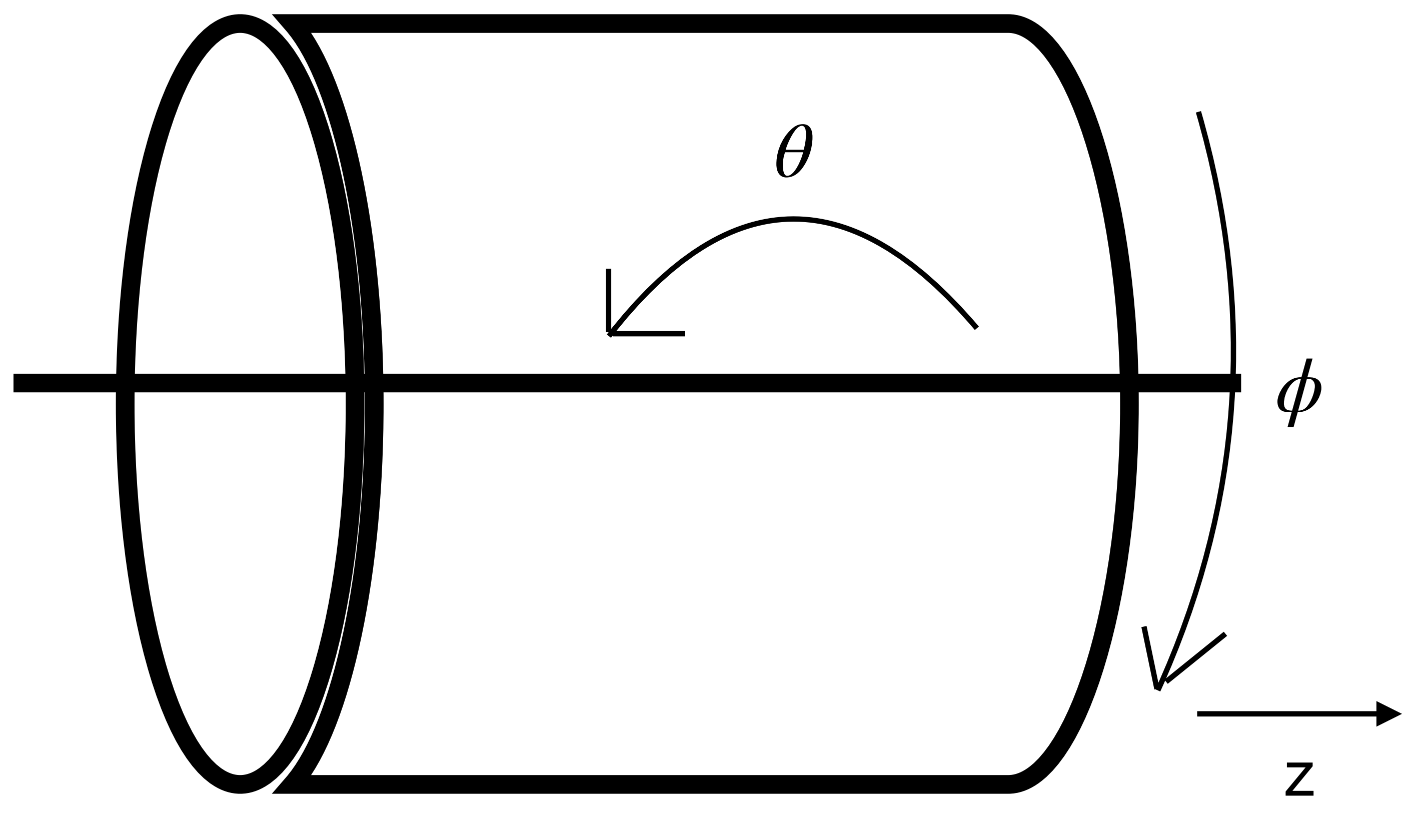
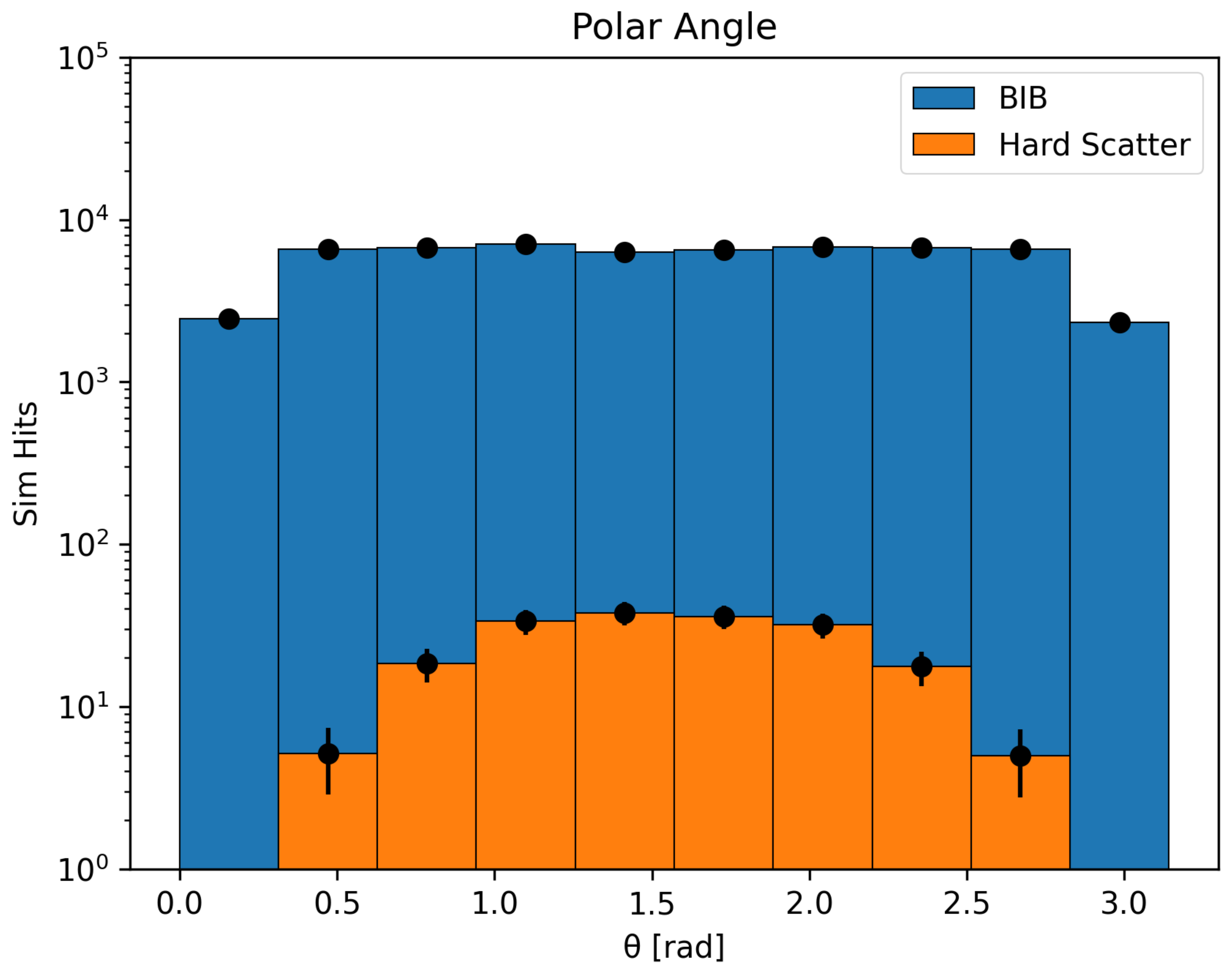
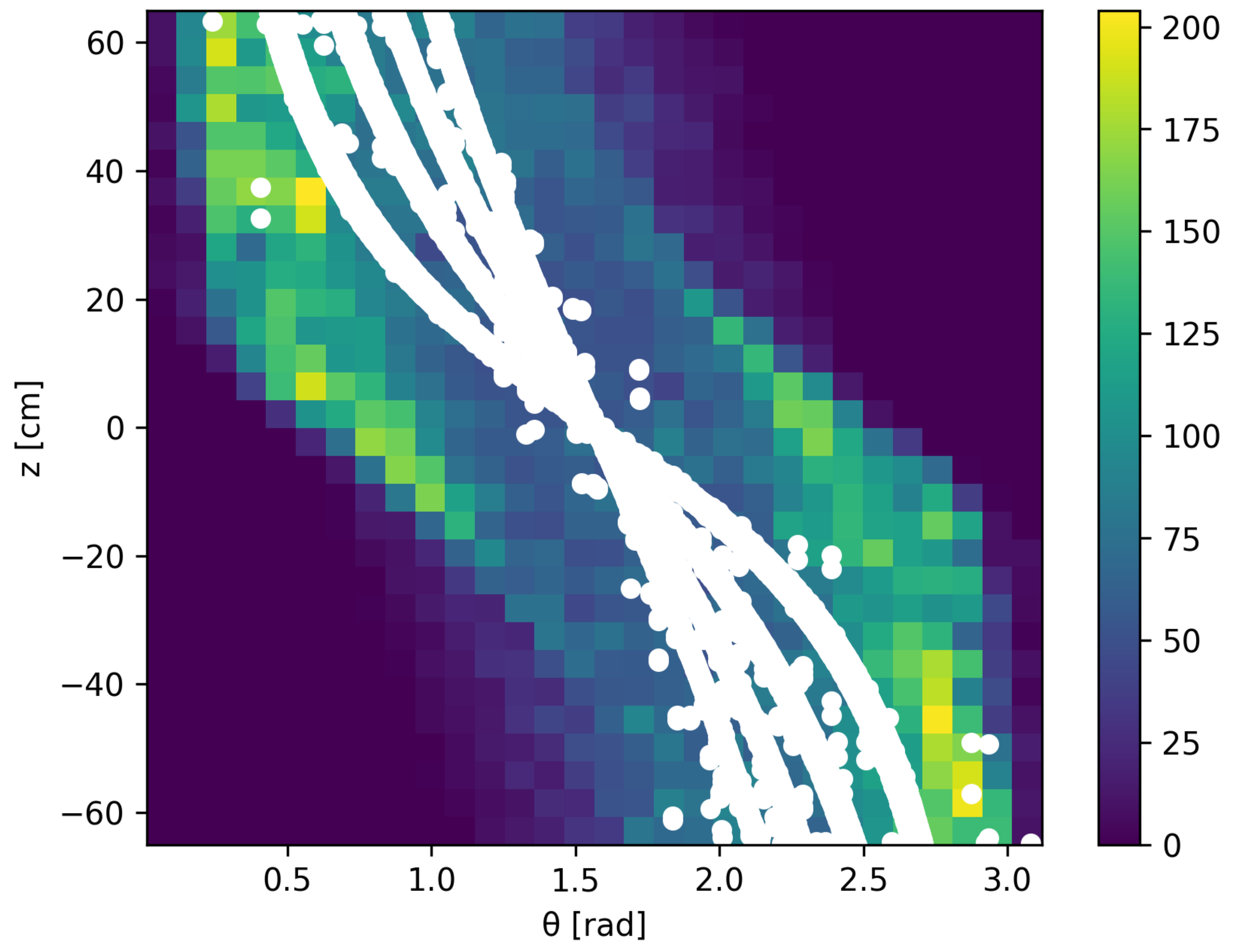
Polar Distribution

- Let's check the polar dependence of the BIB
- These plots have the time cut applied to them

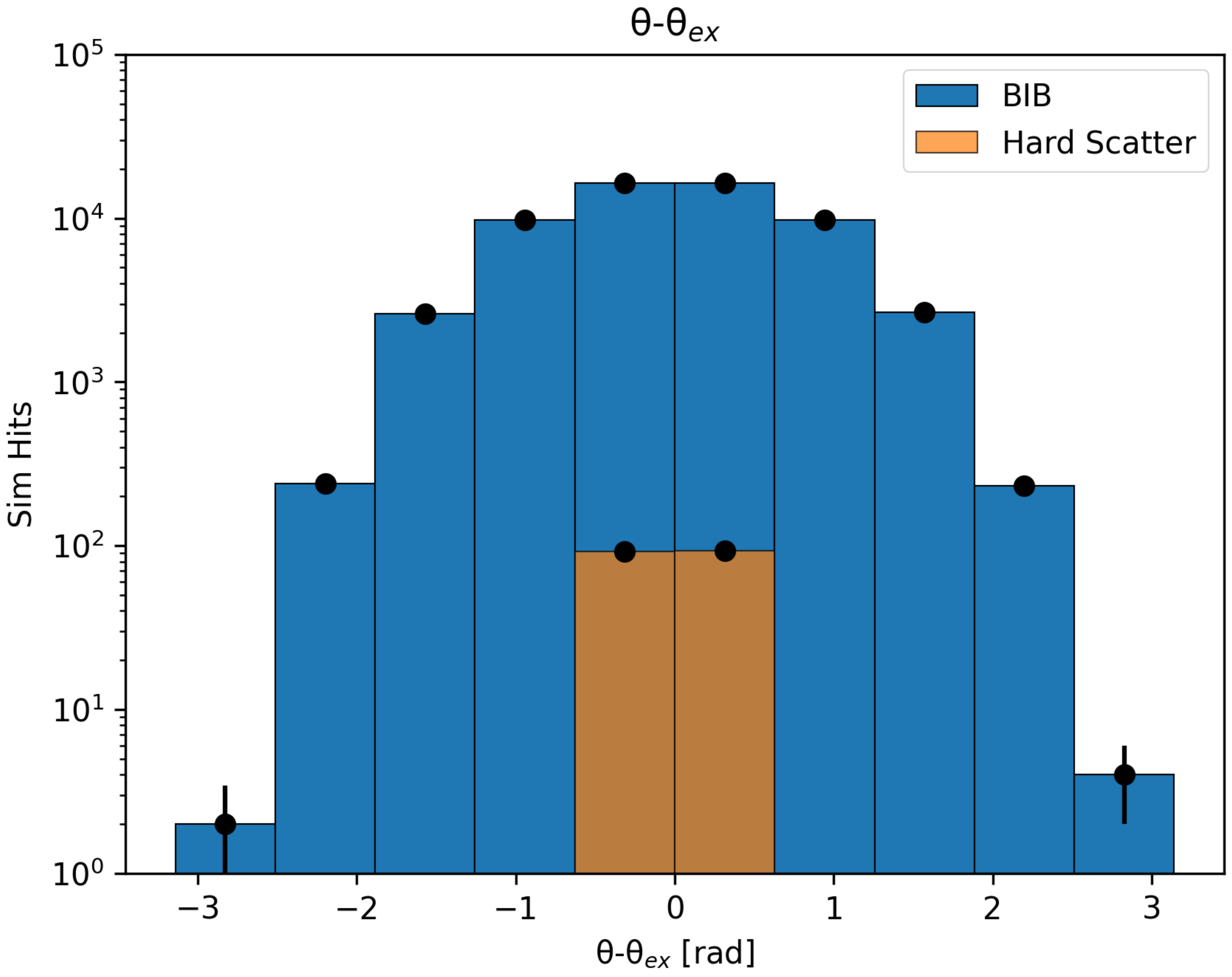


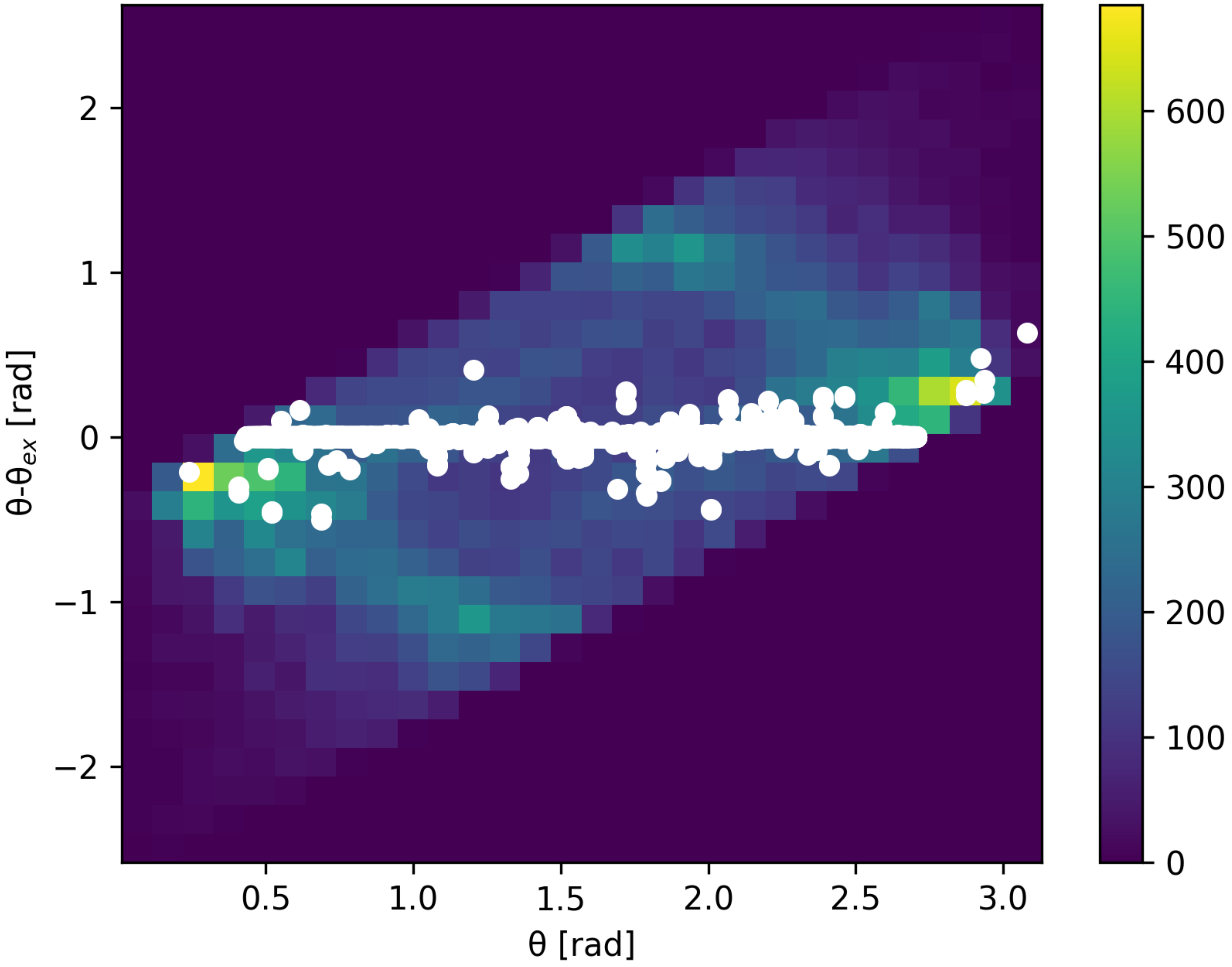
$$\theta = \tan^{-1}\left(\frac{p_r}{p_z}\right)$$

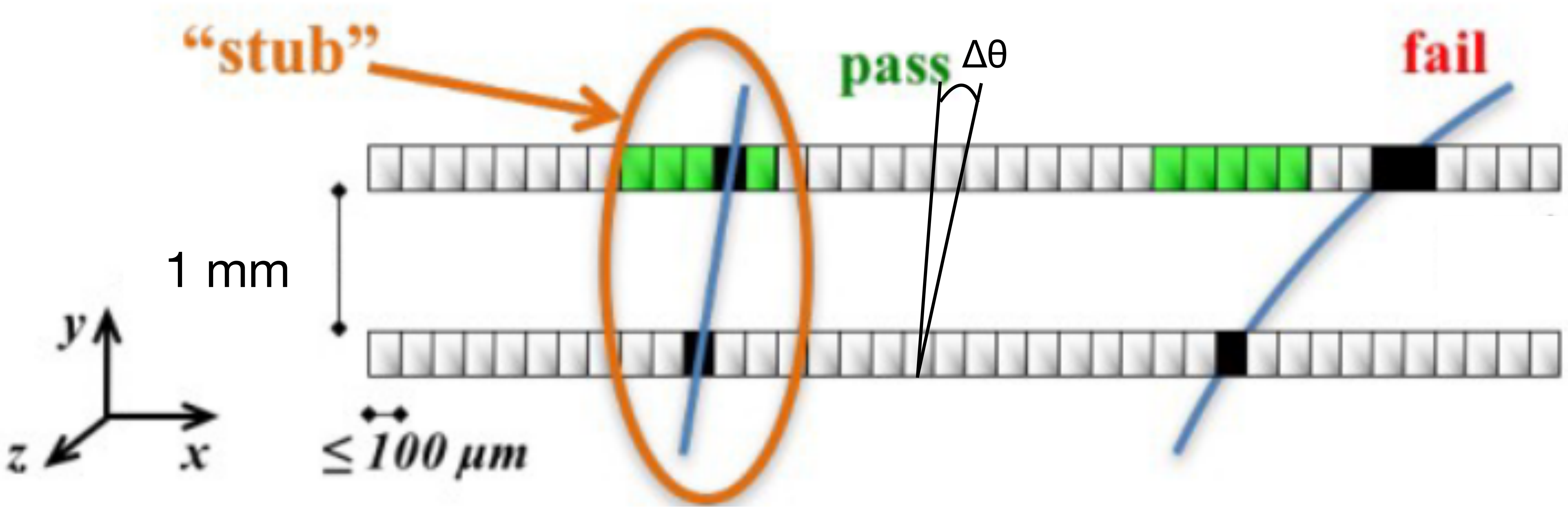




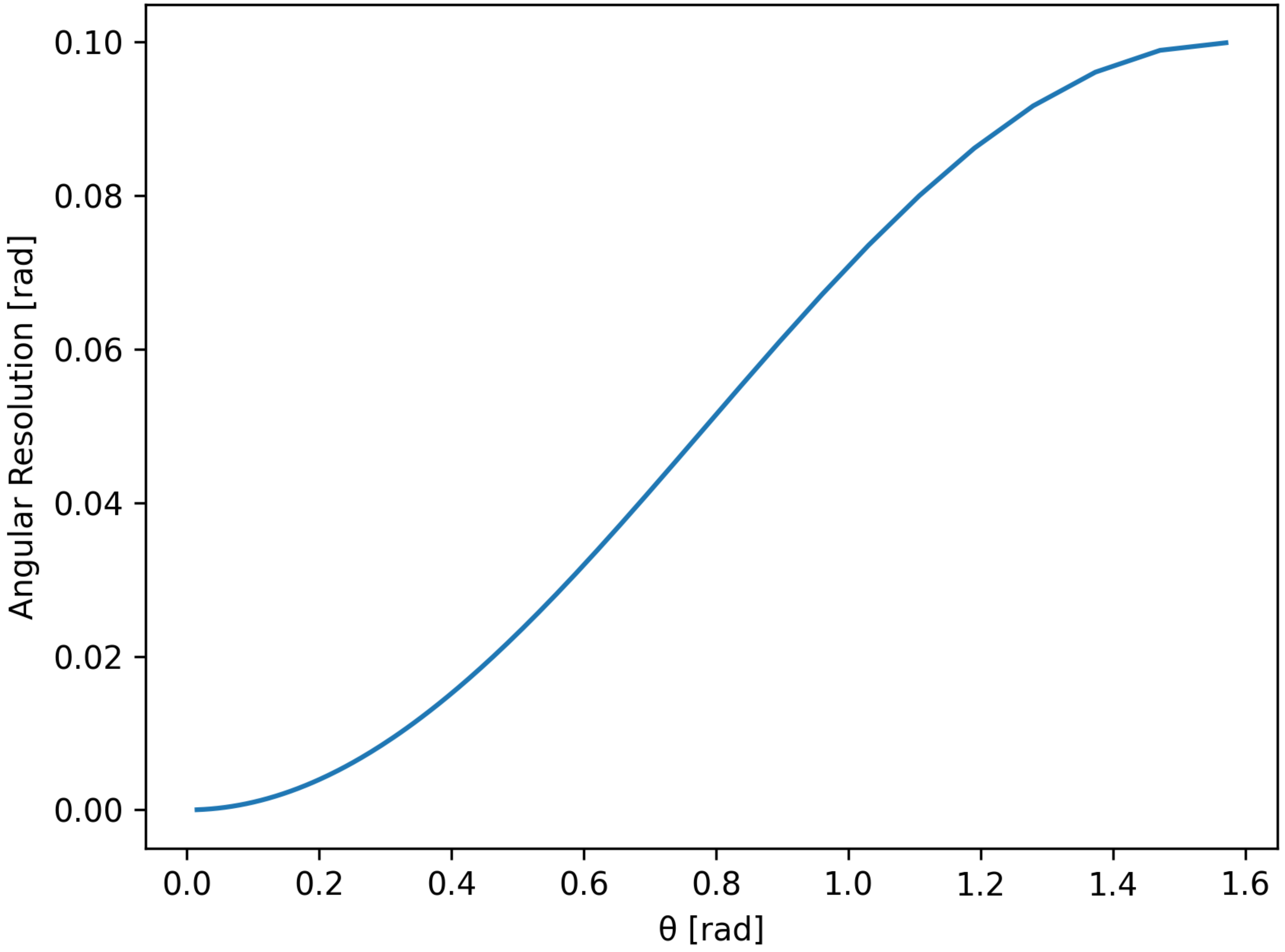
$$\theta_{ex} = \tan^{-1}\left(\frac{R}{Z}\right)$$

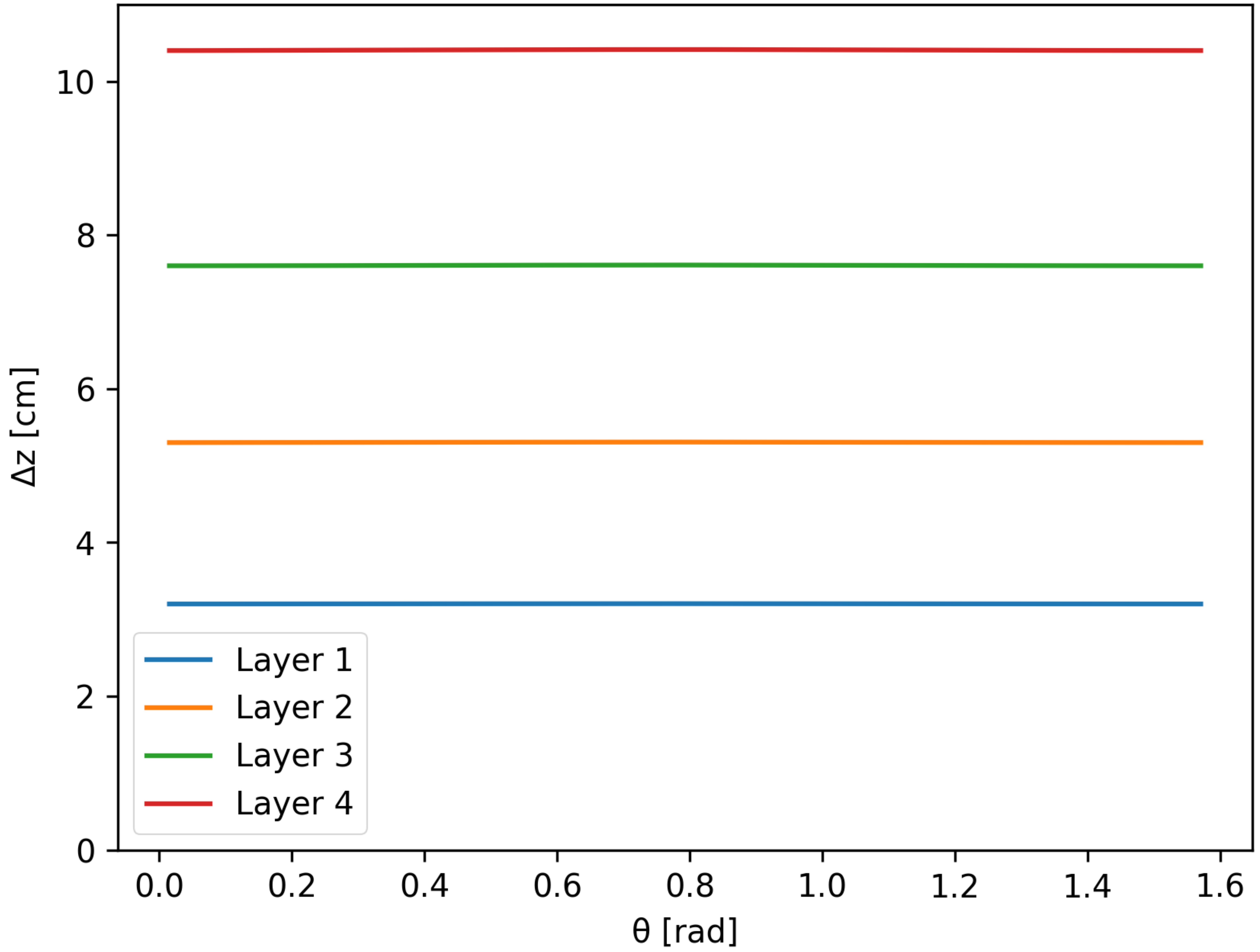






- Ignoring magnetic field effects, assume this sensor layout
- Not sure of angular resolution.





Combined Cuts

$\|\theta - \theta_{ex}\| <$ / $\|$T-ToF$\| <$	No Cut		1 rad		0.1 rad		0.01 rad	
10 ps	95.3%	2.60%	96.3%	2.60%	99.6%	2.65%	99.9%	2.90%
20 ps	90.7%	1.17%	92.7%	1.17%	99.2%	1.22%	99.9%	1.48%
30 ps	86.1%	0.618%	89.2%	0.618%	98.7%	0.669%	99.9%	0.926%
50 ps	77.4%	0.234%	82.7%	0.234%	97.9%	0.289%	99.8%	0.553%
100 ps	57.5%	0.030%	69.0%	0.030%	96.0%	0.089%	99.6%	0.357%
200 ps	23.3%	0.00%	48.8%	0.00%	93.6%	0.059%	99.3%	0.327%

Each column is split into two: the left side represents the percentage of BIB that is removed when we make these cuts, the right side represents the percentage of signal that is removed.

Conclusion

- Using time cuts less than 20 ps and angle cuts less than 0.1 radian we can cut the BIB by 99.2% and only cut 1.22% of the signal.
- We should investigate if these cuts are valid for other mu+ mu- processes.
- Hopefully, this can be used to support a future muon collider.

Thank you!