Effects of Tracker Timing Windows on LLP Direct Detection

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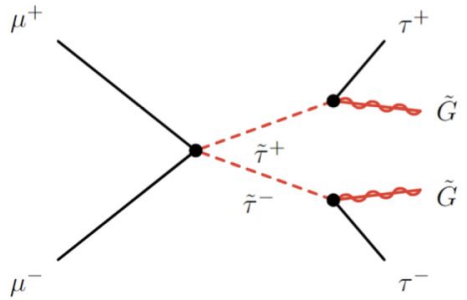
The plan

- Nominal timing windows in the tracker (0.15, 0.30, 0.30 ns for Vertex, Inner, Outer Barrel) allow for BIB mitigation and still allow for reconstruction of SM particles
- Question: within these timing constraints, how efficiently can we hope to detect long-lived BSM particles?

→ Using gauge-mediated supersymmetry breaking model as a benchmark, specifically examining long-lived staus

Disclaimer: studies so far being done with older tracker geometry. Switch to MAIA soon?



Time of travel, window options

Studying masses ranging from 1 - 4.5 TeV, 10ns lifetime.

Recent UChi grad Tate Flicker previously defined three time windows to for future study.

Designed so we have 70% of staus arriving in time to end of IT by Medium, 90% by Loose

→ For efficiency, accepted staus are ones that survive until at least first layer of Inner tracker

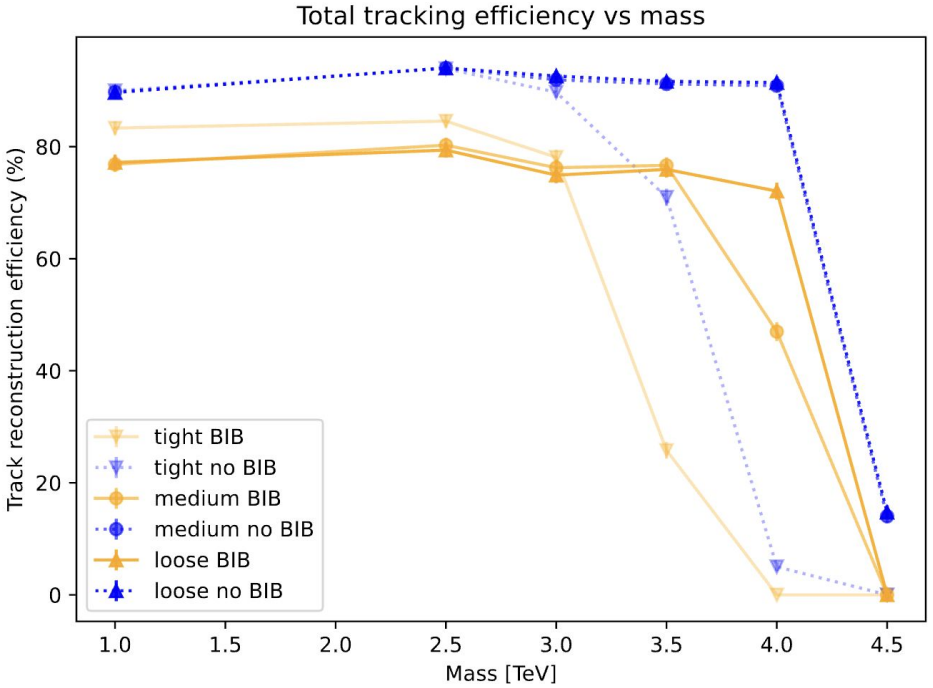
Plan on reassessing these windows

	Time Windows for Further Study		
	Vertex Detector	Inner Tracker	Outer Tracker
Tight (ns)	0.15	0.30	0.30
Medium (ns)	0.32	1.25	4.00
Loose (ns)	0.32	3.30	10.00

Efficiency studies within time windows

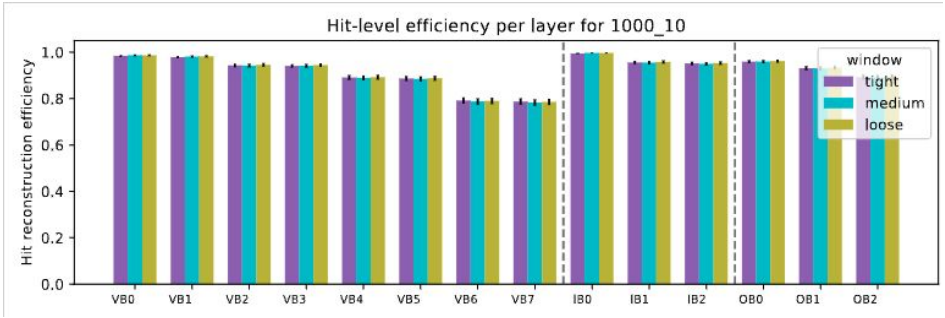
Note: Only 10% BIB here. More on this later.

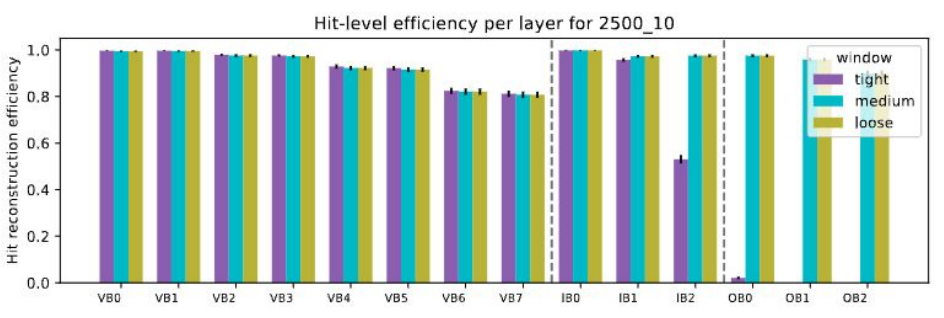
- Steering from mucoll-benchmarks, adding hit-based truth matching with LCRelation
- Ignoring tracks from staus that decay before Inner tracker or have |eta| > 1

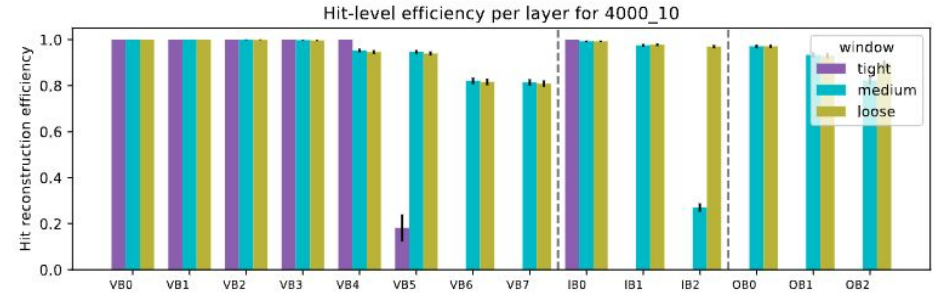


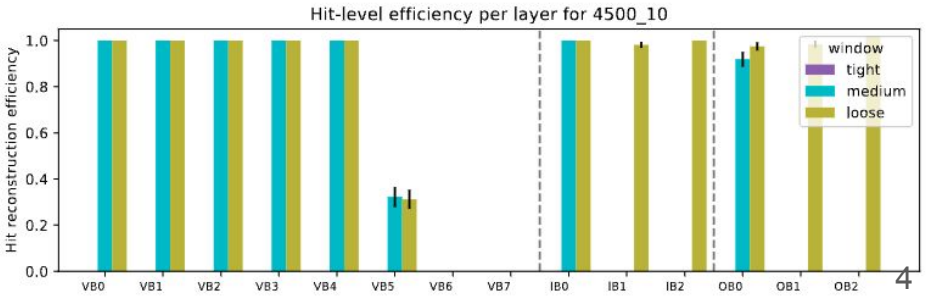
Hit recording efficiency

In tight window, lots of hits aren't being reconstructed.



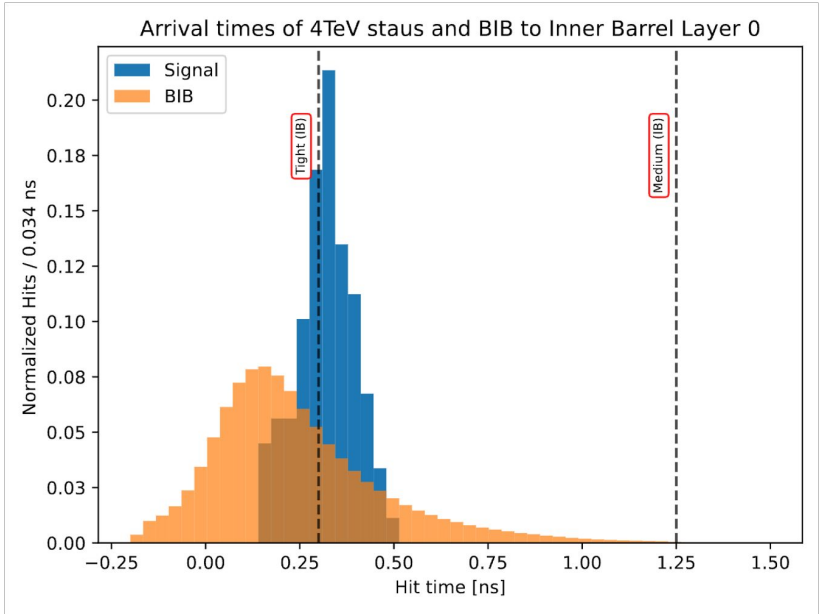






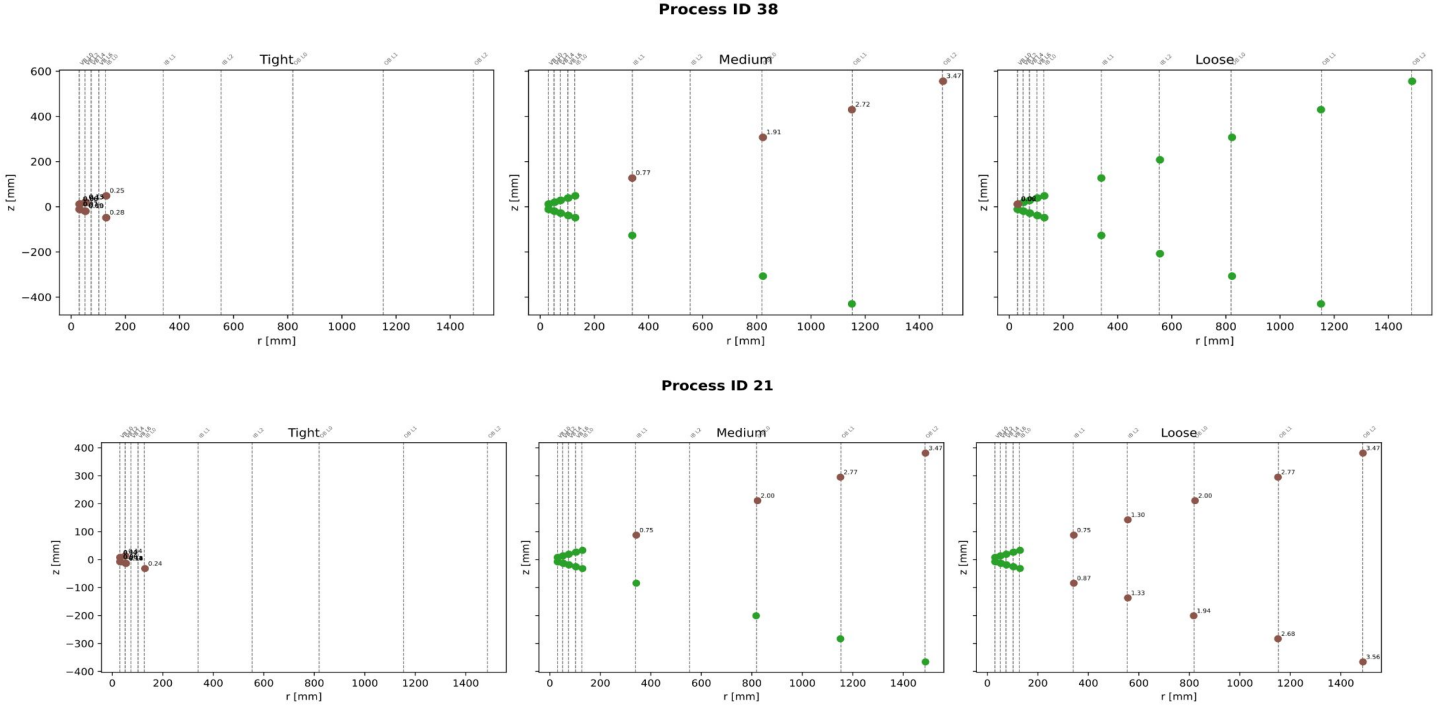
Hit recording efficiency

Makes sense when you think about how long it takes particles to travel to each layer.



Visualizing trajectories in the r-z plane:

(4TeV 10ns Medium) Too many hits to plot BIB. Just looking at if particles have been matched to tracks or not. A couple of surprising cases …

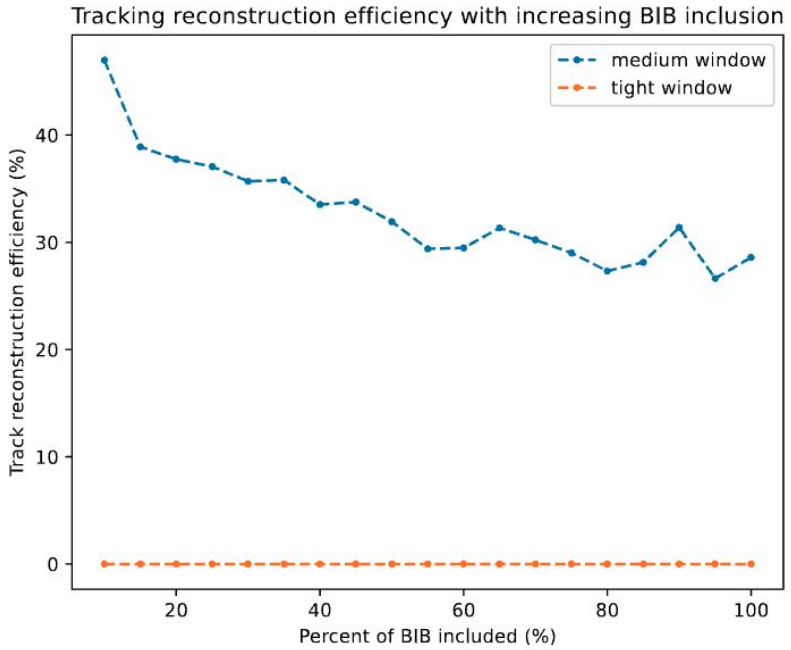


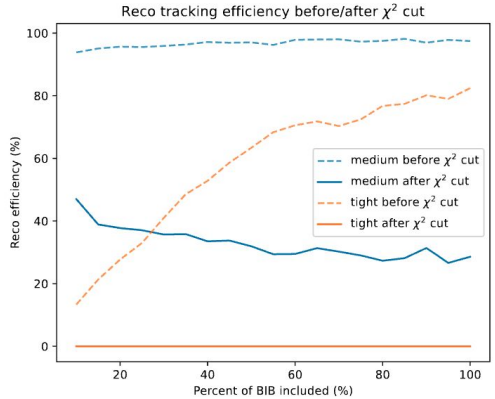
BIB trends

As we add more BIB into the picture, track reconstruction efficiency drops.

Main culprit seems to be bad tracks (chi^2 > 5): BIB hits included in tracks but excluded in efficiency calculation

Then at a certain point there are so many BIB hits that chi^2 can get better.





Motivation for 4-D tracking?

- We're assuming we have timing information from each layer, but it's not currently accounted for in the reconstruction algorithm
- Could help get rid of BIB hits → improve chi^2 → improve efficiency!
- In search of ACTS guidance

Track 231431956, PDG -2000015, Weight = 0.67, Rchi^2 = 132664.856

9 hits in track:

Stau : VXDBarrel 0, 0.087 ns

Stau : VXDBarrel 1, 0.132 ns

Stau : VXDBarrel 2, 0.178 ns

Stau : VXDBarrel 3, 0.179 ns

Stau : VXDEndcap 0, 0.237 ns

Stau : ITBarrel 0, 0.507 ns

(bib particle) : ITBarrel 1, 0.172 ns

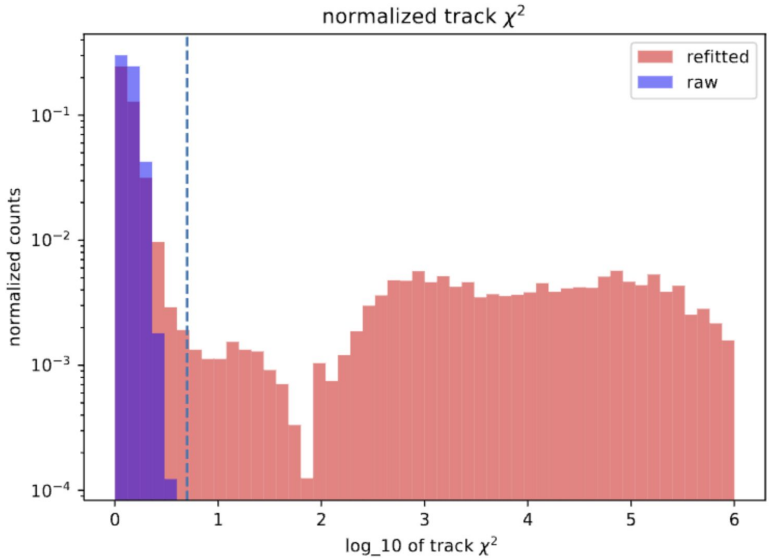
(bib particle) : OTBarrel 0, 0.009 ns

(bib particle) : OTEndcap 0, 0.108 ns

ATL-PHYS-PUB-2023-023 and arXiv:2412.14136v1

Refit Processor Issues

Some BIB hits being removed (good), but chi^2 value jumping up very far for no apparent reason.

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REFIT: track 2408285, PDG  2000015, weight=0.73, rchi^2 = 1771.56
11 hits in track:
REFIT track info:
Pt = 1.5098142063402553
2000015: VXDBarrel0, at 0.05ns, (-25.81, -16.51, 0.83), cov: (0.0, 0.0, 0.0)
2000015: VXDBarrel1, at 0.02ns, (-27.57, -17.62, 0.89), cov: (0.0, 0.0, 0.0)
2000015: VXDBarrel2, at 0.13ns, (-43.19, -27.61, 1.40), cov: (0.0, 0.0, 0.0)
2000015: VXDBarrel3, at 0.09ns, (-44.91, -28.72, 1.45), cov: (0.0, 0.0, 0.0)
2000015: VXDBarrel4, at 0.18ns, (-62.94, -40.23, 2.04), cov: (0.0, 0.0, 0.0)
2000015: VXDBarrel5, at 0.18ns, (-64.68, -41.35, 2.08), cov: (0.0, 0.0, 0.0)
2000015: VXDBarrel6, at 0.24ns, (-86.11, -55.05, 2.78), cov: (0.0, 0.0, 0.0)
2000015: VXDBarrel7, at 0.18ns, (-87.83, -56.16, 2.83), cov: (0.0, 0.0, 0.0)
BIB: ITBarrel0, at -0.14ns, (-107.96, -72.27, 3.90), cov: (0.0, 0.0, 0.0)
BIB: ITBarrel1, at 0.83ns, (-267.62, -209.67, 9.37), cov: (0.0, 0.0, 0.0)
BIB: ITBarrel2, at 0.42ns, (-411.57, -374.72, 13.75), cov: (0.0, 0.0, 0.0)
 track omega, sig_omega: -0.000708885898347944, 1.4367254400650033e-06
COV: d0: 0.0006278137443587184, phi:7.158837433962617e-07, z0: 0.0006272712489590049, tan lambda: 7.131091592782468e-07

PRE-REFIT: track 28090, PDG  2000015, weight=0.57, rchi^2 = 1.32
14 hits in track:
PRE-REFIT track info:
Pt = 1.4780132784152973
2000015: VXDBarrel0, at 0.05ns, (-25.81, -16.51, 0.83), cov: (0.0, 0.0, 0.0)
2000015: VXDBarrel1, at 0.02ns, (-27.57, -17.62, 0.89), cov: (0.0, 0.0, 0.0)
2000015: VXDBarrel2, at 0.13ns, (-43.19, -27.61, 1.40), cov: (0.0, 0.0, 0.0)
2000015: VXDBarrel3, at 0.09ns, (-44.91, -28.72, 1.45), cov: (0.0, 0.0, 0.0)
2000015: VXDBarrel4, at 0.18ns, (-62.94, -40.23, 2.04), cov: (0.0, 0.0, 0.0)
2000015: VXDBarrel5, at 0.18ns, (-64.68, -41.35, 2.08), cov: (0.0, 0.0, 0.0)
2000015: VXDBarrel6, at 0.24ns, (-86.11, -55.05, 2.78), cov: (0.0, 0.0, 0.0)
2000015: VXDBarrel7, at 0.18ns, (-87.83, -56.16, 2.83), cov: (0.0, 0.0, 0.0)
BIB: ITBarrel0, at -0.14ns, (-107.96, -72.27, 3.90), cov: (0.0, 0.0, 0.0)
BIB: ITBarrel1, at 0.83ns, (-267.62, -209.67, 9.37), cov: (0.0, 0.0, 0.0)
BIB: ITBarrel2, at 0.42ns, (-411.57, -374.72, 13.75), cov: (0.0, 0.0, 0.0)
BIB: OTBarrel0, at 0.71ns, (-542.18, -618.70, 20.58), cov: (0.0, 0.0, 0.0)
BIB: OTBarrel1, at 0.66ns, (-632.26, -962.02, 44.12), cov: (0.0, 0.0, 0.0)
BIB: OTBarrel2, at 1.43ns, (-663.71, -1331.62, 41.14), cov: (0.0, 0.0, 0.0)
omega, sig_omega -0.00072413828456774 35 1.6243680112569923e-06
COV: d0: 0.00022182511747814715, phi:1.918309777693139e-07, z0: 0.0002201354072894901, tan lambda: 1.856339935102369e-07
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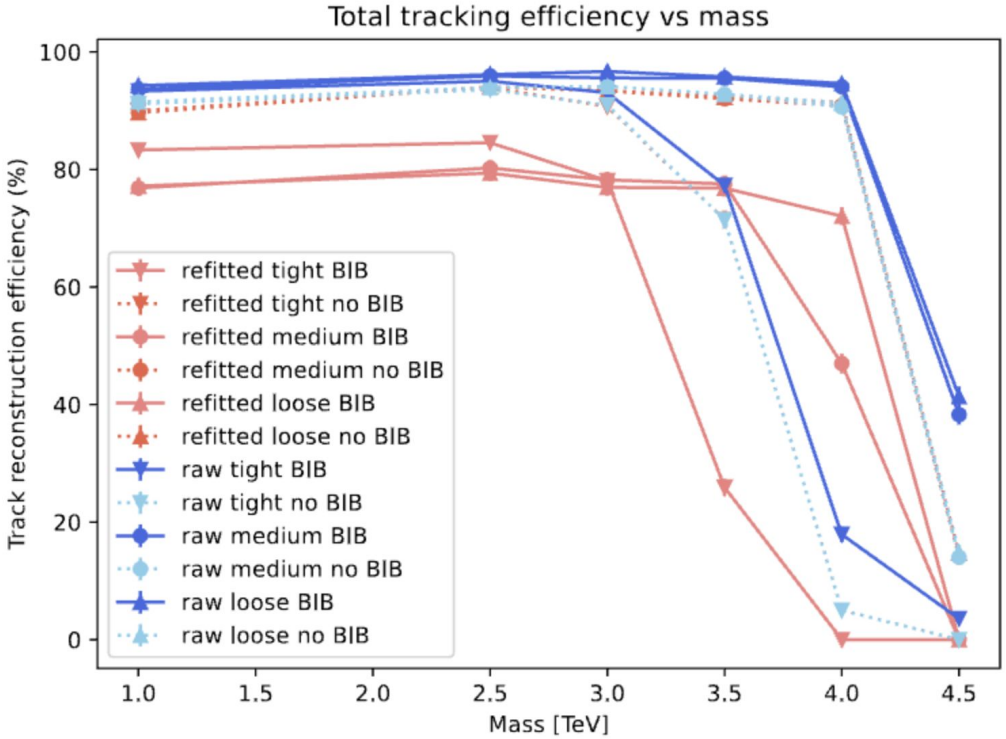
Refit issues cont.

As a result, switched from requiring 3.5 hits in a track to 7 hits in a track.

New results coming soon!



Conclusions + next steps

- Nominal timing windows: great for BIB, but leave much to be desired in terms of efficiency for stau direct detection
- Losing efficiency with more forgiving windows because BIB hits sneak in, raise chi^2.
- Looking into 4D track reconstruction
- Fix refitting?
- Re-analyzing in MAIA geometry soon.
- Cone BIB processor in reco? → New BIB lattice
- Reassess timing windows + make recommendations.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