



# SPEEDING UP THE TRACKING CODE

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[github issue 117](#)

# EVIO TO LCIO PROFILING: TRACKER RECON DRIVER

org.hps.recon.tracking.TrackerReconDriver. <b>process</b> (org.lcsim.event.EventHeader)	40,578 ms (72%)	400
org.lcsim.util.Driver. <b>process</b> (org.lcsim.event.EventHeader)	40,573 ms (72%)	400
org.lcsim.util.Driver. <b>processChildren</b> (org.lcsim.event.EventHeader)	40,573 ms (72%)	400
org.lcsim.util.Driver. <b>doProcess</b> (org.lcsim.event.EventHeader)	40,573 ms (72%)	400
org.lcsim.recon.tracking.seedtracker.SeedTracker. <b>process</b> (org.lcsim.event.EventHeader)	40,573 ms (71.9%)	400
org.lcsim.recon.tracking.seedtracker.SeedTrackFinder. <b>FindTracks</b> (org.lcsim.recon.tracking.seedtracker.SeedStrategy, double)	39,555 ms (70.1%)	400
org.lcsim.recon.tracking.seedtracker.ConfirmerExtender. <b>Extend</b> (org.lcsim.recon.tracking.seedtracker.SeedCandidate, org.lcsim.recon.tracking.seedtracker.SeedCandidate)	30,205 ms (53.6%)	12004
org.lcsim.recon.tracking.seedtracker.ConfirmerExtender. <b>doTask</b> (org.lcsim.recon.tracking.seedtracker.SeedCandidate, org.lcsim.recon.tracking.seedtracker.SeedCandidate)	30,186 ms (53.5%)	12004
org.lcsim.recon.tracking.seedtracker.HelixFitter. <b>FitCandidate</b> (org.lcsim.recon.tracking.seedtracker.SeedCandidate, org.lcsim.recon.tracking.seedtracker.SeedCandidate)	18,066 ms (32%)	78366
org.hps.recon.tracking.MultipleScattering. <b>FindScatters</b> (org.lcsim.fit.helicaltrack.HelicalTrackFit)	16,777 ms (29.8%)	50830
org.hps.recon.tracking.MultipleScattering. <b>FindHPSScatters</b> (org.lcsim.fit.helicaltrack.HelicalTrackFit)	16,770 ms (29.7%)	50830
org.hps.recon.tracking.MultipleScattering. <b>FindHPSScatterPoints</b> (org.lcsim.fit.helicaltrack.HelicalTrackFit)	16,735 ms (29.7%)	50830
org.hps.recon.tracking.MultipleScattering. <b>getHelixIntersection</b> (org.lcsim.fit.helicaltrack.HelicalTrackFit, org.hps.recon.tracking.MultipleScattering)	15,247 ms (27%)	1829880
org.lcsim.recon.tracking.seedtracker.FastCheck. <b>CheckHitSeed</b> (org.lcsim.fit.helicaltrack.HelicalTrackHit, org.lcsim.recon.tracking.seedtracker.FastCheck)	12,298 ms (17.4%)	137476
org.lcsim.recon.tracking.seedtracker.FastCheck. <b>TwoPointCircleCheck</b> (org.lcsim.fit.helicaltrack.HelicalTrackHit, org.lcsim.recon.tracking.seedtracker.FastCheck)	12,183 ms (17.3%)	625258

I investigated speeding up:

- `getHelixIntersection`
- `TwoPointCircleCheck`

## HELIX INTERSECTION: CURRENT CODE

- For each track seed (starting with hits triplet), Extend calls findHPSScatterPoints for each possible track extension into each subsequent layer
- For each possible track extension, findHPSScatterPoints calls getHelixIntersection for each sensor
- getHelixIntersection steps:
  - Approximate calculation of helix intersection pt with sensor plane
  - Determine whether intersection pt falls within boundaries of sensor, +/- **isInside tolerance** (1 mm)
  - If so, proceed to iterative calculation (convergence precision  $\epsilon = 10^{-4}$  mm, typically requires 2-3 iterations)
  - Determine whether more precise intersection pt is within boundaries of sensor

# HELIX INTERSECTION: MODIFYING THE CODE

org.hps.recon.tracking.MultipleScattering.getHelixIntersection (org.lcsim.fit.helicaltrack.HelicalTrackFit, org.hps.recon.tracking.TrackUtils)		15,145 ms (26.9%)	1829880
org.hps.recon.tracking.TrackUtils.getHelixPlaneIntercept (org.lcsim.fit.helicaltrack.HelicalTrackFit, hep.physics.vec.Hep3Vector)	iterative	4,429 ms (7.9%)	638006
org.hps.recon.tracking.WTrack.getHelixAndPlaneIntercept (hep.physics.vec.Hep3Vector, hep.physics.vec.Hep3Vector)		2,688 ms (4.8%)	638006
org.hps.recon.tracking.WTrack.getHelixParametersAtPathLength (double, hep.physics.vec.Hep3Vector)		1,152 ms (2%)	638006
org.hps.recon.tracking.WTrack.<init> (org.lcsim.fit.helicaltrack.HelicalTrackFit, double)		463 ms (0.8%)	638006
hep.physics.vec.VecOp.inverse (hep.physics.vec.Hep3Matrix)	[goat]	4,364 ms (7.7%)	4297766
org.lcsim.detector.Transform3D.transformed (hep.physics.vec.Hep3Vector)		1,486 ms (2.6%)	4297766
org.lcsim.fit.helicaltrack.HelixUtils.PathToXPlane (org.lcsim.fit.helicaltrack.HelicalTrackFit, double, double, int)		1,354 ms (2.4%)	1829880

- I reduced #calls to getHelixIntersection by skipping sensors in layers >3 we know the track won't hit
  - Assume the track hits *top* or *bottom* but not both
  - Assume track cannot hit both *hole* and *slot* in same half-module
- I added dolterative switch to getHelixIntersection: when off, only performs approximate calculation
  - Turned it off for Extend steps, but back on for final track fits

## TWO POINT CIRCLE CHECK: CURRENT CODE

- For each valid pair of sectors (determined by Sectoring) in seed layers (dictated by Strategy), algorithm goes through every possible hit pair
  - constructs circle through the two points + max helix DCA
  - then examines arc length and  $(r, z)$  of points
- Fundamentally different from standard ATLAS / CMS pair-finding that limits initial combinatorics
  - for each hit in outer sector, uses  $[\phi + \text{max DCA}]$  to set a limited  $\phi$  range of hits in inner sector to examine
  - then examines  $z$  of points

## TWO POINT CIRCLE CHECK: MODIFYING THE CODE

org.lcsim.recon.tracking.seedtracker.FastCheck. <b>CheckHitSeed</b> (org.lcsim.fit.helicaltrack.HelicalTrackHit, org.lcsim.recon	12,298 ms (17.4%)	137476
org.lcsim.recon.tracking.seedtracker.FastCheck. <b>TwoPointCircleCheck</b> (org.lcsim.fit.helicaltrack.HelicalTrackHit, org.l	12,183 ms (17.3%)	625258
org.lcsim.recon.tracking.seedtracker.FastCheck. <b>CorrectHitPosition</b> (org.lcsim.fit.helicaltrack.HelicalTrackHit, org.l	11,159 ms (15.8%)	1250516
org.lcsim.fit.twopointcircle.TwoPointCircleFitter. <b>FitCircle</b> (org.lcsim.event.TrackerHit, org.lcsim.event.TrackerHit, c	551 ms (0.8%)	625258

- I considered replacing current algorithm with ATLAS / CMS pair-finding, but current algorithm performs well despite combinatorics disadvantage
- Most TwoPointCircleCheck time is taken by CorrectHitPosition
  - CheckHitSeed checks a hit (to maybe add to track seed) against every existing hit in seed, calling TwoPointCircleCheck(hitToMaybeAdd, hitExisting) in loop over all hitExisting
  - TwoPointCircleCheck corrects positions of hitToMaybeAdd and hitExisting, independently... calculating same correction on hitToMaybeAdd for each hitExisting
  - Calculating correction on hitToMaybeAdd only once per seed cuts execution time in ~half

# ASSESSMENT

- Total time savings according to profiler
- Approximate vs iterative results for individual helix intersection points
- Performance studies: to discuss
  - What quantities (impact parameters? residuals?)
  - Designating “standard” files (data? MC?) for benchmarking

# TIME SAVINGS

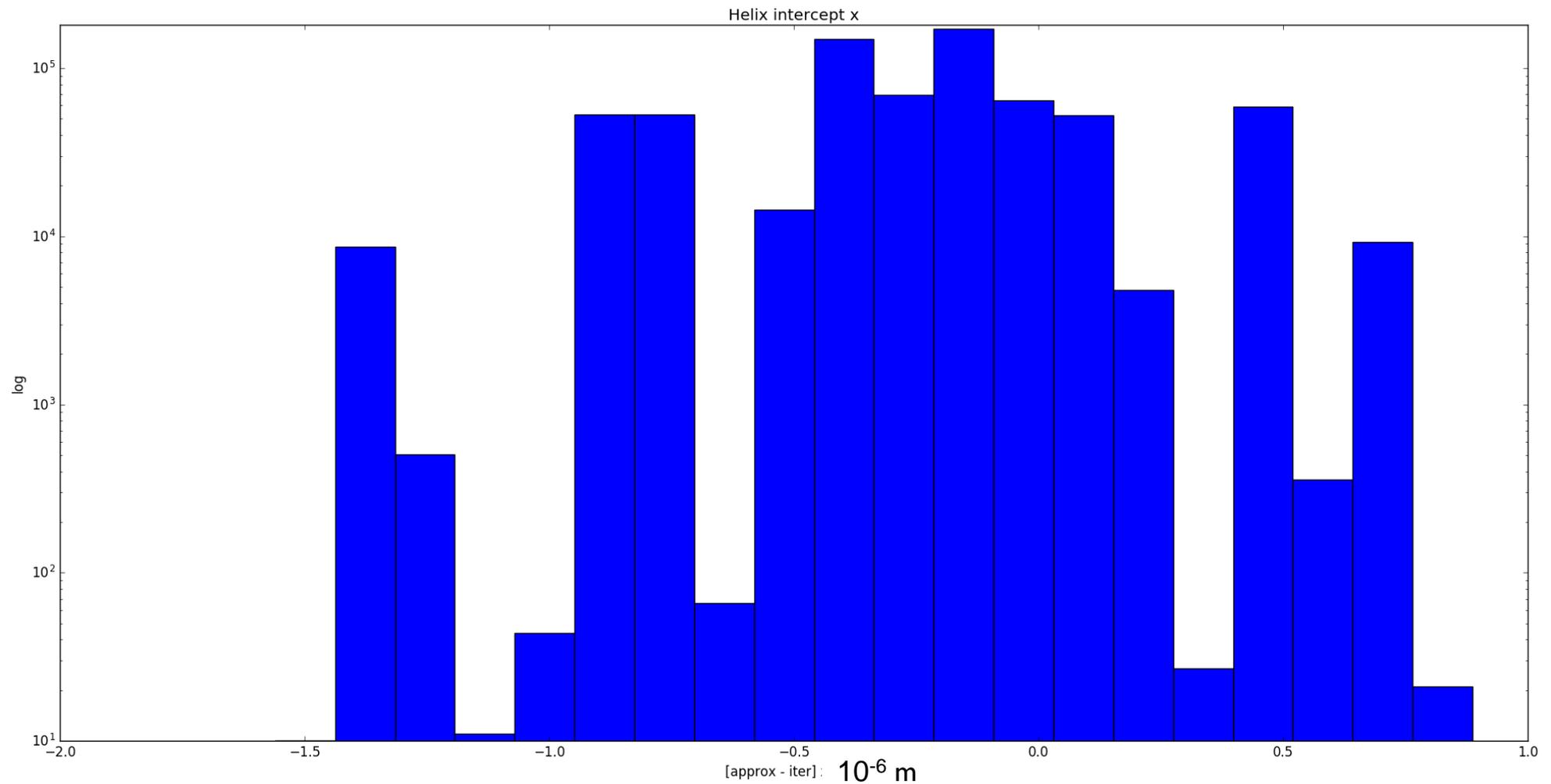
org.hps.recon.tracking.TrackerReconDriver.process (org.lcsim.event.EventHeader)	56,790 ms (80.5%)	400
org.lcsim.util.Driver.process (org.lcsim.event.EventHeader)	56,785 ms (80.5%)	400
org.lcsim.util.Driver.processChildren (org.lcsim.event.EventHeader)	56,785 ms (80.5%)	400
org.lcsim.util.Driver.doProcess (org.lcsim.event.EventHeader)	56,784 ms (80.5%)	400
org.hps.recon.tracking.SeedTracker.process (org.lcsim.event.EventHeader)	56,784 ms (80.5%)	400
org.lcsim.recon.tracking.seedtracker.SeedTrackFinder.FindTracks (org.lcsim.recon.tracking.seedtracker.SeedStrategy, double)	54,992 ms (78%)	400
org.lcsim.recon.tracking.seedtracker.ConfirmerExtender.Extend (org.lcsim.recon.tracking.seedtracker.SeedCandidate, org.lcsim.recon.tracking.seedtracker.SeedCandidate)	43,557 ms (61.8%)	13838
org.lcsim.recon.tracking.seedtracker.ConfirmerExtender.doTask (org.lcsim.recon.tracking.seedtracker.SeedCandidate, org.lcsim.recon.tracking.seedtracker.SeedCandidate)	43,537 ms (61.7%)	13838
org.lcsim.recon.tracking.seedtracker.HelixFitter.FitCandidate (org.lcsim.recon.tracking.seedtracker.SeedCandidate, org.lcsim.recon.tracking.seedtracker.HelixFitter)	27,662 ms (39.2%)	113142
org.hps.recon.tracking.MultipleScattering.FindScatters (org.lcsim.fit.helicaltrack.HelicalTrackFit)	25,688 ms (36.4%)	70696
org.hps.recon.tracking.MultipleScattering.FindHPSScatters (org.lcsim.fit.helicaltrack.HelicalTrackFit)	25,679 ms (36.4%)	70696
org.hps.recon.tracking.MultipleScattering.FindHPSScatterPoints (org.lcsim.fit.helicaltrack.HelicalTrackFit)	25,624 ms (36.3%)	70696
org.hps.recon.tracking.MultipleScattering.getHelixIntersection (org.lcsim.fit.helicaltrack.HelicalTrackFit, org.lcsim.recon.tracking.seedtracker.HelixFitter)	23,190 ms (32.9%)	2545056

Current

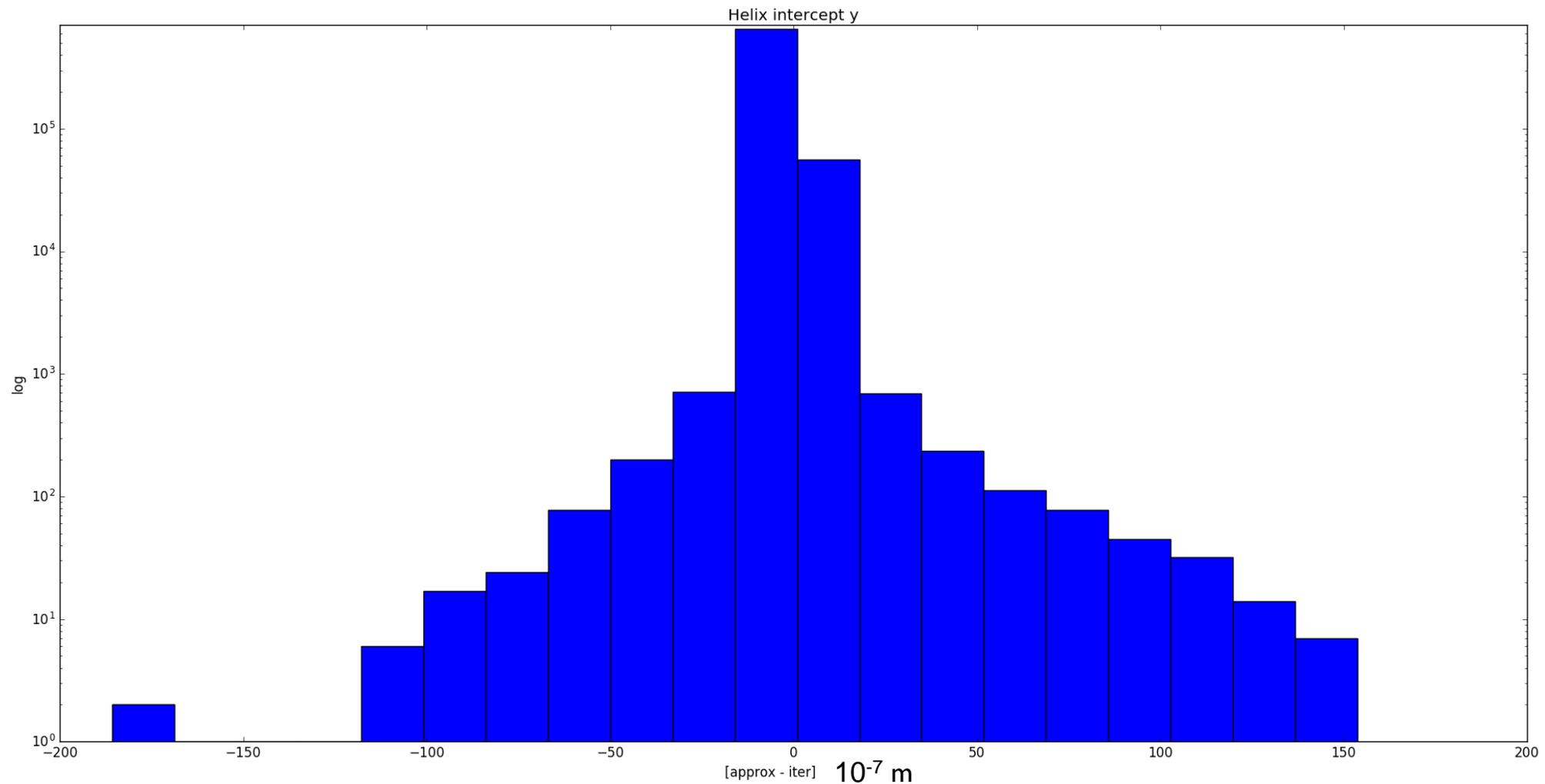
org.hps.recon.tracking.TrackerReconDriver.process (org.lcsim.event.EventHeader)	42,735 ms (71%)	400
org.lcsim.util.Driver.process (org.lcsim.event.EventHeader)	42,729 ms (71%)	400
org.lcsim.util.Driver.processChildren (org.lcsim.event.EventHeader)	42,729 ms (71%)	400
org.lcsim.util.Driver.doProcess (org.lcsim.event.EventHeader)	42,729 ms (71%)	400
org.hps.recon.tracking.SeedTracker.process (org.lcsim.event.EventHeader)	42,728 ms (71%)	400
org.lcsim.recon.tracking.seedtracker.SeedTrackFinder.FindTracks (org.lcsim.recon.tracking.seedtracker.SeedStrategy, double)	41,025 ms (68.2%)	400
org.lcsim.recon.tracking.seedtracker.ConfirmerExtender.Extend (org.lcsim.recon.tracking.seedtracker.SeedCandidate, org.lcsim.recon.tracking.seedtracker.SeedCandidate)	31,159 ms (51.8%)	13762
org.lcsim.recon.tracking.seedtracker.ConfirmerExtender.doTask (org.lcsim.recon.tracking.seedtracker.SeedCandidate, org.lcsim.recon.tracking.seedtracker.SeedCandidate)	31,137 ms (51.8%)	13762
org.lcsim.recon.tracking.seedtracker.HelixFitter.FitCandidate (org.lcsim.recon.tracking.seedtracker.SeedCandidate, org.lcsim.recon.tracking.seedtracker.HelixFitter)	13,517 ms (22.5%)	112442
org.hps.recon.tracking.MultipleScattering.FindScatters (org.lcsim.fit.helicaltrack.HelicalTrackFit)	11,622 ms (19.3%)	70263
org.hps.recon.tracking.MultipleScattering.FindHPSScatters (org.lcsim.fit.helicaltrack.HelicalTrackFit)	11,613 ms (19.3%)	70263
org.hps.recon.tracking.MultipleScattering.FindHPSScatterPoints (org.lcsim.fit.helicaltrack.HelicalTrackFit)	11,565 ms (19.2%)	70263
org.hps.recon.tracking.MultipleScattering.getHelixIntersection (org.lcsim.fit.helicaltrack.HelicalTrackFit, org.lcsim.recon.tracking.seedtracker.HelixFitter)	6,490 ms (10.8%)	1702812

Modified

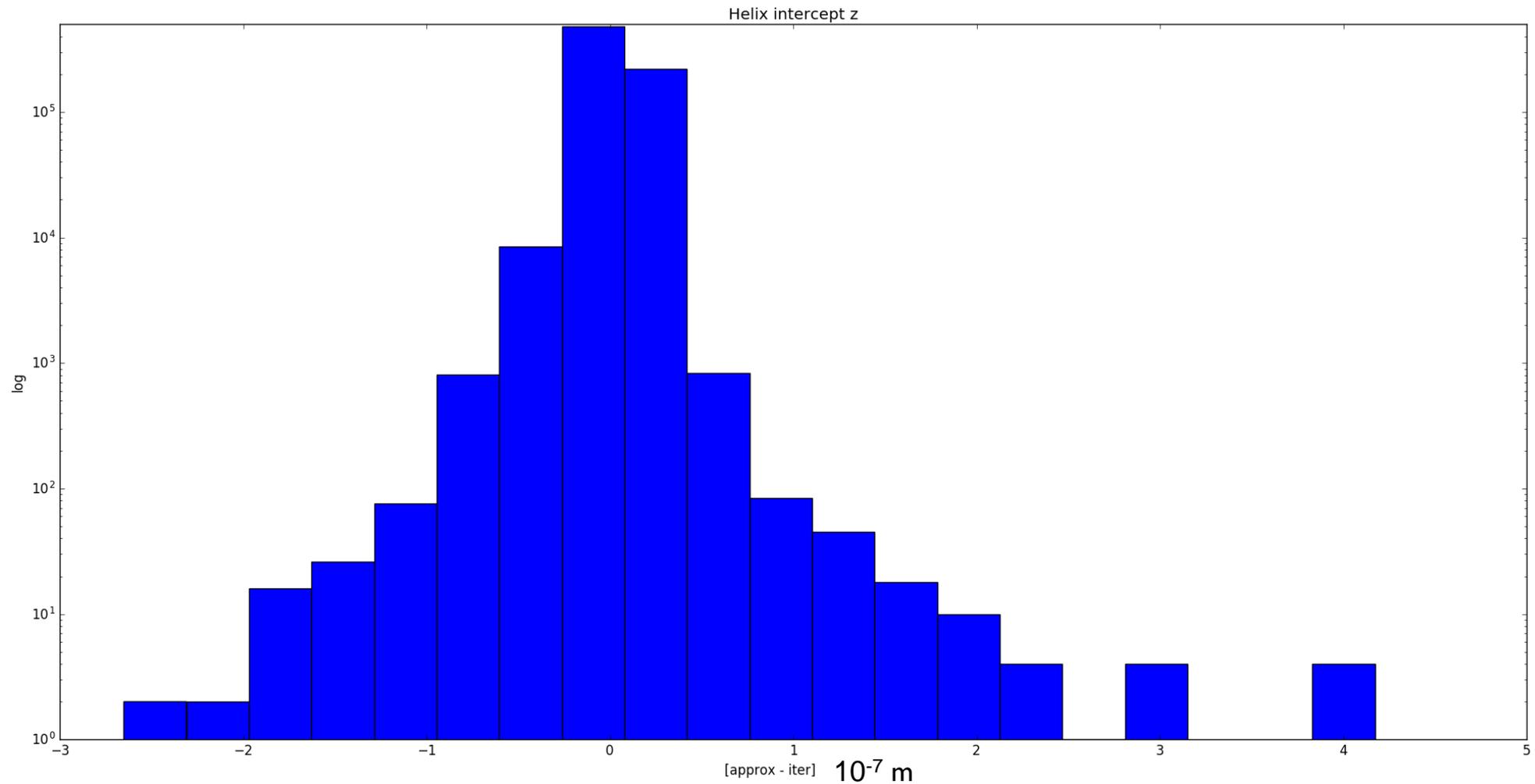
# APPROXIMATE VS ITERATIVE : HELIX INTERSECTION POINTS



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# HELIX MULTIPLE SCATTERING ERROR

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**github issue 126**

## CURRENT CODE

- `org.lcsim.recon.tracking.seedtracker.FastCheck` ► `ThreePointHelixCheck`  
triplet-finding for track seeds

- For each of the 3 hits, calculates contribution to *z error*

```
if (hit instanceof HelicalTrack3DHit)
    dztot += _nsig * ((HelicalTrack3DHit) hit).dz();
else {
    zfirst = false;
    if (hit instanceof HelicalTrack2DHit)
        dztot += ((HelicalTrack2DHit) hit).zlen() / 2.;
    else
        dztot += _nsig * Math.sqrt(hit.getCovMatrix()[5]);
}
```

- **Then** `// Add multiple scattering error here - for now, just set it to 1 mm`  
`dztot += 1.;`

- Compares *total z error* to (*predicted – actual*) *z position* of middle hit

```
if (Math.abs(zpred - z[1]) > dztot) return false;
```

# MODIFYING MULTIPLE SCATTERING ERROR TERM

- Replace 1. with quick approximation based on
  - Momentum estimate
    - Radius of curvature and slope of 3-point helix (already calculated in method)
    - B-field (already required as input to method)
  - Thickness (constant) of an SVT sensor
  - Distances between hits