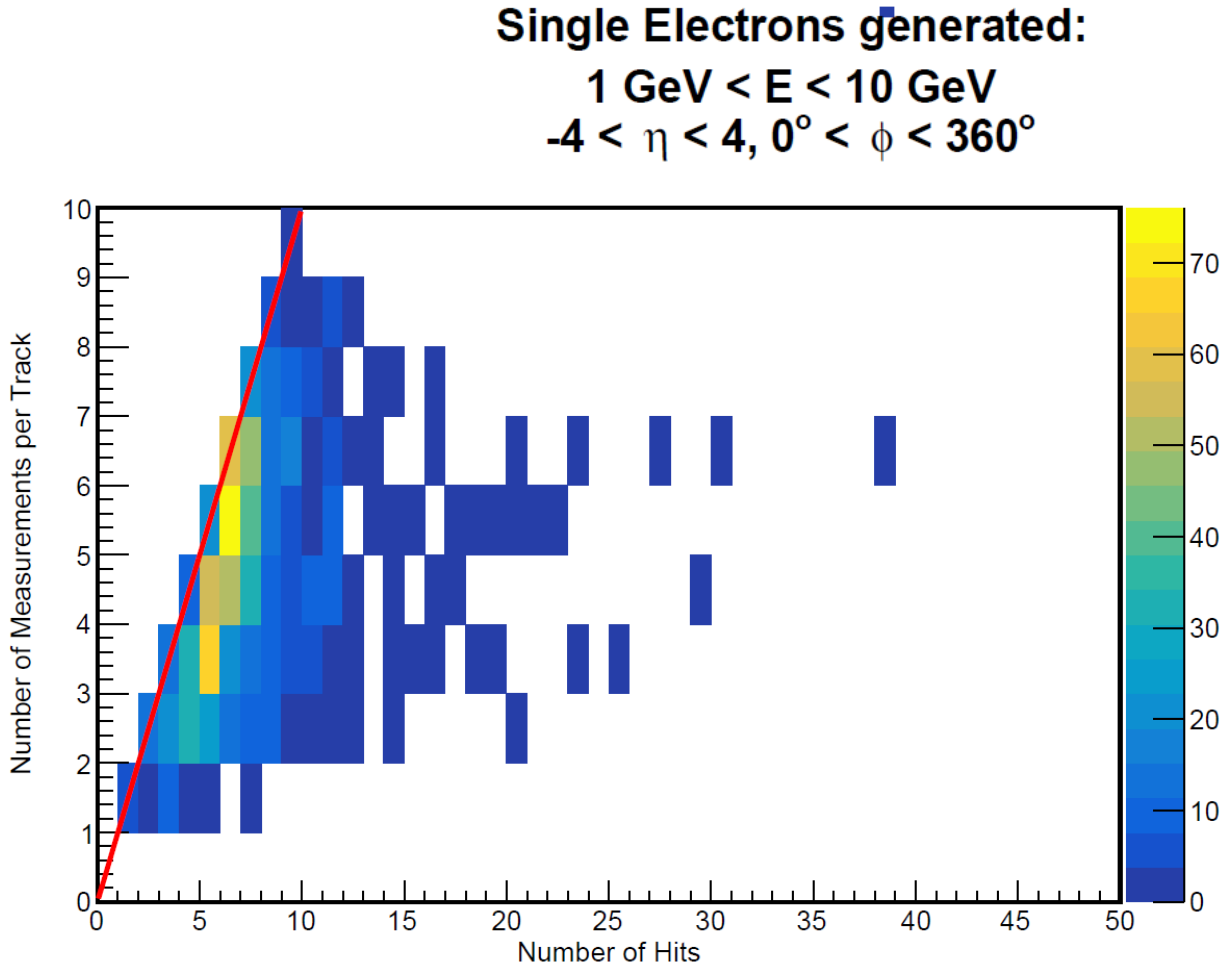
Geant-level hits in tracking detectors and *EICRecon* digitization algorithms

Barak Schmookler

Motivation



- We want to better understand why we see more digitized hits in the tracking detector than hits used in the fitted track (for single-particle simulation with truth seeded track).
- We also want to understand why we regularly find nearly duplicate seeds.
- Lastly, we want to understand how the Geant hits in the tracking detector are digitized and turned into space points for the track fitting.

Tracker hits in Geant (DD4Hep) output

VertexBarrelHits = (vector<edm4hep::SimTrackerHitData>)0x393a8f0

VertexBarrelHits.cellID = 1740106435056286543, 1705175386151526863, 1495786141957038595, 1740106434626789814, 1747368519520192131, 1742724194859871055, 1743906370864200118, 1744413049444599017, 1745989302871728156, 1743512326942144540, 1621126990317978857, 1619775894108891983, 1619072194211710185

VertexBarrelHits.EDep = 0.000050, 0.000011, 0.000018, 0.000011, 0.000106, 0.000013, 0.000025, 0.000037, 0.000023, 0.000078, 0.000010, 0.000014, 0.000085

VertexBarrelHits.time = 0.172631, 0.230277, 0.575604, 0.172684, 0.198817, 0.222128, 0.233706, 0.249430, 0.262780, 0.276989, 0.534295, 0.538136, 0.540672

VertexBarrelHits.pathLength = 0.057513, 0.057520, 0.057511, 0.041903, 0.278637, 0.044581, 0.038396, 0.041919, 0.043550, 0.143896, 0.016068, 0.007537, 0.051001

VertexBarrelHits.quality = 0, 0, 0, 1073741824, 1073741824, 1073741824, 1073741824, 1073741824, 1073741824, 1073741824, 1073741824, 1073741824, 1073741824

VertexBarrelHits.position.x = -30.1701, -40.2047, -100.186, -30.1782, -28.8245, -27.4767, -28.8427, -27.407, -28.6091, -27.4422, -27.6744, -27.9173, -28.1112

VertexBarrelHits.position.y = 19.6455, 26.2272, 66.0554, 19.6389, 21.6014, 23.2667, 21.5396, 23.3516, 21.8583, 23.3087, 22.9942, 22.6983, 22.4739

VertexBarrelHits.position.z = 37.1742, 49.5744, 123.963, 37.1548, 34.5338, 36.2218, 35.8026, 35.616, 35.0633, 35.9978, 79.4242, 79.9155, 80.156

VertexBarrelHits.momentum.x = -3.186112, -3.182194, -3.162133, -0.000774, -0.000237, 0.000247, -0.000520, 0.000420, -0.000402, 0.000224, -0.000031, -0.000141, -0.000099

VertexBarrelHits.momentum.y = 2.085773, 2.090894, 2.121809, 0.000138, -0.000261, -0.000596, 0.000243, -0.000375, 0.000280, -0.000111, -0.000036, -0.000159, -0.000061

VertexBarrelHits.momentum.z = 3.934102, 3.934191, 3.933759, -0.000174, -0.000110, 0.000081, -0.000105, -0.000062, -0.000001, 0.000263, 0.000295, 0.000229, 0.000103

VertexBarrelHits#0 = (vector<podio::ObjectID>)0x39835b0

VertexBarrelHits#0.index = 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0

VertexBarrelHits#0.collectionID = 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1

Commas delimit the hits in detector

Tracker hits in Geant (DD4Hep) output

VertexBarrelHits = (vector<edm4hep::SimTrackerHitData>)0x393a8f0

VertexBarrelHits.cellID = 1740106435056286543, 1705175386151526863, 14
1742724194859871055, 1743906370864200118, 1744413049444599017, 1
1619775894108891983, 1619072194211710185

VertexBarrelHits.EDep = 0.000050, 0.000011, 0.000018, 0.000011, 0.000106, 0.

VertexBarrelHits.time = 0.172631, 0.230277, 0.575604, 0.172684, 0.198817, 0.2

VertexBarrelHits.pathLength = 0.057513, 0.057520, 0.057511, 0.041903, 0.2786

VertexBarrelHits.quality = 0, 0, 0, 1073741824, 1073741824, 1073741824, 1073

VertexBarrelHits.position.x = -30.1701, -40.2047, -100.186, -30.1782, -28.8245,

VertexBarrelHits.position.y = 19.6455, 26.2272, 66.0554, 19.6389, 21.6014, 23.2

VertexBarrelHits.position.z = 37.1742, 49.5744, 123.963, 37.1548, 34.5338, 36.2

VertexBarrelHits.momentum.x = -3.186112, -3.182194, -3.162133, -0.000774, -0

VertexBarrelHits.momentum.y = 2.085773, 2.090894, 2.121809, 0.000138, -0.000261, -0.000596, 0.000243, -0.000375, 0.000280, -0.000111, -0.000036, -0.000159, -0.000061

VertexBarrelHits.momentum.z = 3.934102, 3.934191, 3.933758, -0.000174, -0.000110, 0.000081, -0.000105, -0.000062, -0.000001, 0.000263, 0.000295, 0.000229, 0.000103

VertexBarrelHits#0 = (vector<podio::ObjectID>)0x39835b0

VertexBarrelHits#0.index = 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0

VertexBarrelHits#0.collectionID = 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1

MCParticles = (vector<edm4hep::MCParticleData>)0x340c710
MCParticles.PDG = 11, 11, 22, 11
MCParticles.generatorStatus = 1, 0, 0, 0
MCParticles.simulatorStatus = 16777216, 1493172224, 1358954496, 1493172224
MCParticles.charge = -1.000000, -1.000000, 0.000000, -1.000000
MCParticles.time = 0.000000, 2.127509, 3.376798, 3.537263
MCParticles.mass = 0.000510999, 0.000510999, 0, 0.000510999
MCParticles.vertex.x = 0, -364.581, -571.663, -597.841
MCParticles.vertex.y = 0, 252.174, 409.991, 430.794
MCParticles.vertex.z = 0, 458.511, 727.721, 762.307
MCParticles.endpoint.x = -702.893, -353.818, -671.82, -597.654
MCParticles.endpoint.y = 543.874, 269.065, 489.223, 431.325
MCParticles.endpoint.z = 953.056, 466.876, 859.89, 763.511
MCParticles.momentum.x = -3.197403, -0.001730, -0.027344, -0.000472
MCParticles.momentum.y = 2.071061, 0.003967, 0.021631, -0.000350
MCParticles.momentum.z = 3.933372, 0.003131, 0.036083, 0.001524

https://github.com/key4hep/EDM4hep/blob/master/edm4hep.yaml#L191

Tracker hits in Geant (DD4Hep) output

VertexBarrelHits = (vector<edm4hep::SimTrackerHitData>)0x393a8f0

VertexBarrelHits.cellID = 1740106435056286543, 1705175386151526863, 14
1742724194859871055, 1743906370864200118, 1744413049444599017, 1
1619775894108891983, 1619072194211710185

VertexBarrelHits.EDep = 0.000050, 0.000011, 0.000018, 0.000011, 0.000106, 0.

VertexBarrelHits.time = 0.172631, 0.230277, 0.575604, 0.172684, 0.198817, 0.2

VertexBarrelHits.pathLength = 0.057513, 0.057520, 0.057511, 0.041903, 0.278

VertexBarrelHits.quality = 0, 0, 0, 1073741824, 1073741824, 1073741824, 1073

VertexBarrelHits.position.x = -30.1701, -40.2047, -100.186, -30.1782, -28.8245,

VertexBarrelHits.position.y = 19.6455, 26.2272, 66.0554, 19.6389, 21.6014, 23.2

VertexBarrelHits.position.z = 37.1742, 49.5744, 123.963, 37.1548, 34.5338, 36.2

VertexBarrelHits.momentum.x = -3.186112, -3.182194, -3.162133, -0.000774, -0

VertexBarrelHits.momentum.y = 2.085773, 2.090894, 2.121809, 0.000138, -0.000261, -0.000596, 0.000243, -0.000375, 0.000280, -0.000111, -0.000036, -0.000159, -0.000061

VertexBarrelHits.momentum.z = 3.934102, 3.934191, 3.933759, -0.000174, -0.000110, 0.000081, -0.000105, -0.000062, -0.000001, 0.000263, 0.000295, 0.000229, 0.000103

VertexBarrelHits#0 = (vector<podio::ObjectID>)0x39835b0

VertexBarrelHits#0.index = 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0

VertexBarrelHits#0.collectionID = 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1

MCParticles = (vector<edm4hep::MCParticleData>)0x340c710
MCParticles.PDG = 11, 11, 22, 11
MCParticles.generatorStatus = 1, 0, 0, 0
MCParticles.simulatorStatus = 16777216, 1493172224, 1358954496, 1493172224
MCParticles.charge = -1.000000, -1.000000, 0.000000, -1.000000
MCParticles.time = 0.000000, 2.127509, 3.376798, 3.537263
MCParticles.mass = 0.000510999, 0.000510999, 0, 0.000510999
MCParticles.vertex.x = 0, -364.581, -571.663, -597.841
MCParticles.vertex.y = 0, 252.174, 409.991, 430.794
MCParticles.vertex.z = 0, 458.511, 727.721, 762.307
MCParticles.endpoint.x = -702.893, -353.818, -671.82, -597.654
MCParticles.endpoint.y = 543.874, 269.065, 489.223, 431.325
MCParticles.endpoint.z = 953.056, 466.876, 859.89, 763.511
MCParticles.momentum.x = -3.197403, -0.001730, -0.027344, -0.000472
MCParticles.momentum.y = 2.071061, 0.003967, 0.021631, -0.000350
MCParticles.momentum.z = 3.933372, 0.003131, 0.036083, 0.001524

Indicates with which MC particle the hit is associated. All hits here are associated with the primary particle.

Tracker hits in Geant (DD4Hep) output

https://github.com/AIDASoft/DD4hep/issues/126
https://github.com/AIDASoft/DD4hep/pull/145

VertexBarrelHits = (vector<edm4hep::SimTrackerHitData>)0x393a8f0

VertexBarrelHits.cellID = 1740106435056286543, 1705175386151526863, 1495786141957038595, 1740106434626789814, 1747368519520192131, 1742724194859871055, 1743906370864200118, 1744413049444599017, 1745989302871728156, 1743512326942144540, 1621126990317978857, 1619775894108891983, 1619072194211710185

VertexBarrelHits.EDep = 0.000050, 0.000011, 0.000018, 0.000011, 0.000106, 0.000013, 0.000025, 0.000037, 0.000023, 0.000078, 0.000010, 0.000014, 0.000085

VertexBarrelHits.time = 0.172631, 0.230277, 0.575604, 0.172684, 0.198817, 0.222128, 0.233706, 0.249430, 0.262780, 0.276989, 0.534295, 0.538136, 0.540672

VertexBarrelHits.pathLength = 0.057513, 0.057520, 0.057511, 0.041903, 0.278637, 0.044581, 0.038396, 0.041919, 0.043550, 0.143896, 0.016068, 0.007537, 0.051001

VertexBarrelHits.quality = 0, 0, 0, 1073741824, 1073741824, 1073741824, 1073741824, 1073741824, 1073741824, 1073741824, 1073741824, 1073741824, 1073741824

VertexBarrelHits.position.x = -30.1701, -40.2047, -100.186, -30.1782, -28.8245, -27.4767, -28.8427, -27.407, -28.6091, -27.4422, -27.6744, -27.9173, -28.1112

VertexBarrelHits.position.y = 19.6455, 26.2272, 66.0554, 19.6389, 21.6014, 23.2667, 21.5396, 23.3516, 21.8583, 23.3087, 22.9942, 22.6983, 22.4739

VertexBarrelHits.position.z = 37.1742, 49.5744, 123.963, 37.1548, 34.5338, 36.2218, 35.8026, 35.616, 35.0633, 35.9978, 79.4242, 79.9155, 80.156

VertexBarrelHits.momentum.x = -3.186112, -3.182194, -3.162133, -0.000774, -0.000237, 0.000247, -0.000520, 0.000420, -0.000402, 0.000224, -0.000031, -0.000141, -0.000099

VertexBarrelHits.momentum.y = 2.085773, 2.090894, 2.121809, 0.000138, -0.000261, -0.000596, 0.000243, -0.000375, 0.000280, -0.000111, -0.000036, -0.000159, -0.000061

VertexBarrelHits.momentum.z = 3.934102, 3.934191, 3.933759, -0.000174, -0.000110, 0.000081, -0.000105, -0.000062, -0.000001, 0.000263, 0.000295, 0.000229, 0.000103

VertexBarrelHits#0 = (vector<podio::ObjectID>)0x39835b0

VertexBarrelHits#0.index = 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0

VertexBarrelHits#0.collectionID = 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1

Indicates with which MC particle the hit is associated. All hits here are associated with the primary particle. However, non-zero ‘quality’ means hit is actually associated with a secondary which was not saved to MC Particle list – due to energy threshold for produced secondary (governed by RangeCut) to be saved to MC Particle list.

Tracker hits in Geant (DD4Hep) output

VertexBarrelHits = (vector<edm4hep::SimTrackerHitData>)0x393a8f0

VertexBarrelHits.cellID = 1740106435056286543, 1705175386151526863, 1495786141957038595, 1740106434626789814, 1747368519520192131, 1742724194859871055, 1743906370864200118, 1744413049444599017, 1745989302871728156, 1743512326942144540, 1621126990317978857, 1619775894108891983, 1619072194211710185

VertexBarrelHits.EDep = 0.000050, 0.000011, 0.000018, 0.000011, 0.000106, 0.000013, 0.000025, 0.000037, 0.000023, 0.000078, 0.000010, 0.000014, 0.000085

VertexBarrelHits.time = 0.172631, 0.230277, 0.575604, 0.172684, 0.198817, 0.222128, 0.233706, 0.249430, 0.262780, 0.276989, 0.534295, 0.538136, 0.540672

VertexBarrelHits.pathLength = 0.057513, 0.057520, 0.057511, 0.041903, 0.278637, 0.044581, 0.038396, 0.041919, 0.043550, 0.143896, 0.016068, 0.007537, 0.051001

VertexBarrelHits.quality = 0, 0, 0, 1073741824, 1073741824, 1073741824, 1073741824, 1073741824, 1073741824, 1073741824, 1073741824, 1073741824, 1073741824

VertexBarrelHits.position.x = -30.1701, -40.2047, -100.186, -30.1782, -28.8245, -27.4767, -28.8427, -27.407, -28.6091, -27.4422, -27.6744, -27.9173, -28.1112

VertexBarrelHits.position.y = 19.6455, 26.2272, 66.0554, 19.6389, 21.6014, 23.2667, 21.5396, 23.3516, 21.8583, 23.3087, 22.9942, 22.6983, 22.4739

VertexBarrelHits.position.z = 37.1742, 49.5744, 123.963, 37.1548, 34.5338, 36.2218, 35.8026, 35.616, 35.0633, 35.9978, 79.4242, 79.9155, 80.156

VertexBarrelHits.momentum.x = -3.186112, -3.182194, -3.162133, -0.000774, -0.000237, 0.000247, -0.000520, 0.000420, -0.000402, 0.000224, -0.000031, -0.000141, -0.000099

VertexBarrelHits.momentum.y = 2.085773, 2.090894, 2.121809, 0.000138, -0.000261, -0.000596, 0.000243, -0.000375, 0.000280, -0.000111, -0.000036, -0.000159, -0.000061

VertexBarrelHits.momentum.z = 3.934102, 3.934191, 3.933759, -0.000174, -0.000110, 0.000081, -0.000105, -0.000062, -0.000001, 0.000263, 0.000295, 0.000229, 0.000103

VertexBarrelHits#0 = (vector<podio::ObjectID>)0x39835b0

VertexBarrelHits#0.index = 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0

VertexBarrelHits#0.collectionID = 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1

First 3 hits – with ‘quality’ 0 – are at layer 1, 2, and 3 of the inner vertex detector, respectively.

Tracker hits in Geant (DD4Hep) output

VertexBarrelHits = (vector<edm4hep::SimTrackerHitData>)0x393a8f0

VertexBarrelHits.cellID = 1740106435056286543, 1705175386151526863, 1495786141957038595, 1740106434626789814, 1747368519520192131, 1742724194859871055, 1743906370864200118, 1744413049444599017, 1745989302871728156, 1743512326942144540, 1621126990317978857, 1619775894108891983, 1619072194211710185

VertexBarrelHits.EDep = 0.000050, 0.000011, 0.000018, 0.000011, 0.000106, 0.000013, 0.000025, 0.000037, 0.000023, 0.000078, 0.000010, 0.000014, 0.000085

VertexBarrelHits.time = 0.172631, 0.230277, 0.575604, 0.172684, 0.198817, 0.222128, 0.233706, 0.249430, 0.262780, 0.276989, 0.534295, 0.538136, 0.540672

VertexBarrelHits.pathLength = 0.057513, 0.057520, 0.057511, 0.041903, 0.278637, 0.044581, 0.038396, 0.041919, 0.043550, 0.143896, 0.016068, 0.007537, 0.051001

VertexBarrelHits.quality = 0, 0, 0, 1073741824, 1073741824, 1073741824, 1073741824, 1073741824, 1073741824, 1073741824, 1073741824, 1073741824, 1073741824

VertexBarrelHits.position.x = -30.1701, -40.2047, -100.186, -30.1782, -28.8245, -27.4767, -28.8427, -27.407, -28.6091, -27.4422, -27.6744, -27.9173, -28.1112

VertexBarrelHits.position.y = 19.6455, 26.2272, 66.0554, 19.6389, 21.6014, 23.2667, 21.5396, 23.3516, 21.8583, 23.3087, 22.9942, 22.6983, 22.4739

VertexBarrelHits.position.z = 37.1742, 49.5744, 123.963, 37.1548, 34.5338, 36.2218, 35.8026, 35.616, 35.0633, 35.9978, 79.4242, 79.9155, 80.156

VertexBarrelHits.momentum.x = -3.186112, -3.182194, -3.162133, -0.000774, -0.000237, 0.000247, -0.000520, 0.000420, -0.000402, 0.000224, -0.000031, -0.000141, -0.000099

VertexBarrelHits.momentum.y = 2.085773, 2.090894, 2.121809, 0.000138, -0.000261, -0.000596, 0.000243, -0.000375, 0.000280, -0.000111, -0.000036, -0.000159, -0.000061

VertexBarrelHits.momentum.z = 3.934102, 3.934191, 3.933759, -0.000174, -0.000110, 0.000081, -0.000105, -0.000062, -0.000001, 0.000263, 0.000295, 0.000229, 0.000103

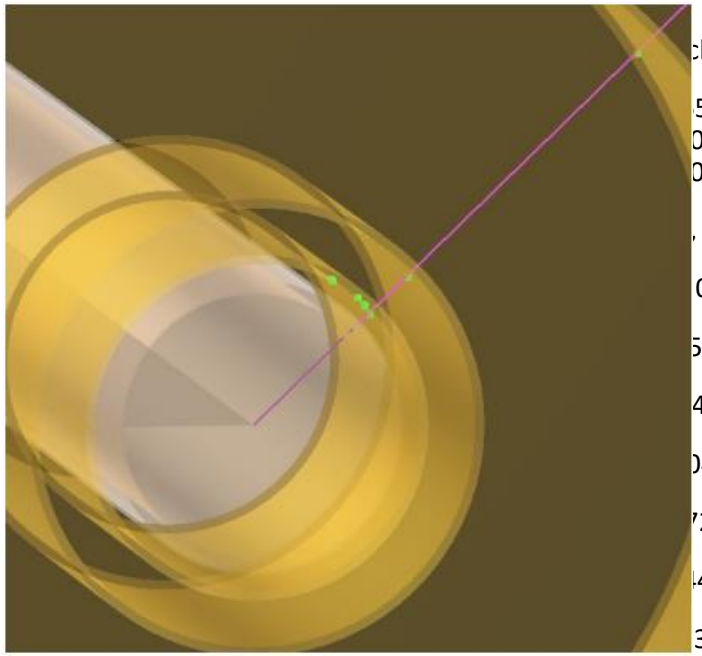
VertexBarrelHits#0 = (vector<podio::ObjectID>)0x39835b0

VertexBarrelHits#0.index = 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0

VertexBarrelHits#0.collectionID = 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1

First 3 hits – with ‘quality’ 0 – are at layer 1, 2, and 3 of the inner vertex detector, respectively.
In this event, other hits seem to be at first layer (r = 36mm).
Some hits are close to primary hit; some are farther away.

Tracker hits in Geant (DD4Hep) output



:kerHitData>)0x393a8f0

5439, 17051753861515268639, 14957861419570385951, 17401064346267898143, 17473685195201921311,
01183, 17444130494445990175, 17459893028717281567, 17435123269421445407, 16211269903179788575,
01855

, 0.000018, 0.000011, 0.000106, 0.000013, 0.000025, 0.000037, 0.000023, 0.000078, 0.000010, 0.000014, 0.000085

0.575604, 0.172684, 0.198817, 0.222128, 0.233706, 0.249430, 0.262780, 0.276989, 0.534295, 0.538136, 0.540672

57520, 0.057511, 0.041903, 0.278637, 0.044581, 0.038396, 0.041919, 0.043550, 0.143896, 0.016068, 0.007537, 0.051001

4, 1073741824, 1073741824, 1073741824, 1073741824, 1073741824, 1073741824, 1073741824, 1073741824, 1073741824

047, -100.186, -30.1782, -28.8245, -27.4767, -28.8427, -27.407, -28.6091, -27.4422, -27.6744, -27.9173, -28.1112

72, 66.0554, 19.6389, 21.6014, 23.2667, 21.5396, 23.3516, 21.8583, 23.3087, 22.9942, 22.6983, 22.4739

4, 123.963, 37.1548, 34.5338, 36.2218, 35.8026, 35.616, 35.0633, 35.9978, 79.4242, 79.9155, 80.156

3.182194, -3.162133, -0.000774, -0.000237, 0.000247, -0.000520, 0.000420, -0.000402, 0.000224, -0.000031, -0.000141, -0.000099

VertexBarrelHits.momentum.y = 2.085773, 2.090894, 2.121809, 0.000138, -0.000261, -0.000596, 0.000243, -0.000375, 0.000280, -0.000111, -0.000036, -0.000159, -0.000061

VertexBarrelHits.momentum.z = 3.934102, 3.934191, 3.933759, -0.000174, -0.000110, 0.000081, -0.000105, -0.000062, -0.000001, 0.000263, 0.000295, 0.000229, 0.000103

VertexBarrelHits#0 = (vector<podio::ObjectID>)0x39835b0

VertexBarrelHits#0.index = 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0

VertexBarrelHits#0.collectionID = 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1

First 3 hits – with ‘quality’ 0 – are at layer 1, 2, and 3 of the inner vertex detector, respectively.
In this event, other hits seem to be at first layer (r = 36mm).
Some hits are close to primary hit; some are farther away.

Tracker hits in Geant (DD4Hep) output

VertexBarrelHits = (vector<edm4hep::SimTrackerHitData>)0x393a8f0

VertexBarrelHits.cellID = 1740106435056286543, 1705175386151526863, 1495786141957038595, 1740106434626789814, 1747368519520192131, 1742724194859871055, 1743906370864200118, 1744413049444599017, 1745989302871728156, 1743512326942144540, 1621126990317978857, 1619775894108891983, 1619072194211710185

VertexBarrelHits.EDep = 0.000050, 0.000011, 0.000018, 0.000011, 0.000106, 0.000013, 0.000025, 0.000037, 0.000023, 0.000078, 0.000010, 0.000014, 0.000085

VertexBarrelHits.time = 0.172631, 0.230277, 0.575604, 0.172684, 0.198817, 0.222128, 0.233706, 0.249430, 0.262780, 0.276989, 0.534295, 0.538136, 0.540672

VertexBarrelHits.pathLength = 0.057513, 0.057520, 0.057511, 0.041903, 0.278637, 0.044581, 0.038396, 0.041919, 0.043550, 0.143896, 0.016068, 0.007537, 0.051001

VertexBarrelHits.quality = 0, 0, 0, 1073741824, 1073741824, 1073741824, 1073741824, 1073741824, 1073741824, 1073741824, 1073741824, 1073741824, 1073741824

VertexBarrelHits.position.x = -30.1701, -40.2047, -100.186, -30.1782, -28.8245, -27.4767, -28.8427, -27.407, -28.6091, -27.4422, -27.6744, -27.9173, -28.1112

VertexBarrelHits.position.y = 19.6455, 26.2272, 66.0554, 19.6389, 21.6014, 23.2667, 21.5396, 23.3516, 21.8583, 23.3087, 22.9942, 22.6983, 22.4739

VertexBarrelHits.position.z = 37.1742, 49.5744, 123.963, 37.1548, 34.5338, 36.2218, 35.8026, 35.616, 35.0633, 35.9978, 79.4242, 79.9155, 80.156

VertexBarrelHits.momentum.x = -3.186112, -3.182194, -3.162133, -0.000774, -0.000237, 0.000247, -0.000520, 0.000420, -0.000402, 0.000224, -0.000031, -0.000141, -0.000099

VertexBarrelHits.momentum.y = 2.085773, 2.090894, 2.121809, 0.000138, -0.000261, -0.000596, 0.000243, -0.000375, 0.000280, -0.000111, -0.000036, -0.000159, -0.000061

VertexBarrelHits.momentum.z = 3.934102, 3.934191, 3.933759, -0.000174, -0.000110, 0.000081, -0.000105, -0.000062, -0.000001, 0.000263, 0.000295, 0.000229, 0.000103

VertexBarrelHits#0 = (vector<podio::ObjectID>)0x39835b0

VertexBarrelHits#0.index = 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0

VertexBarrelHits#0.collectionID = 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1

Deposited energy is similar order of magnitude for all hits.

Another example event – TOF detector

TOFBarrelHits = (vector<edm4hep::SimTrackerHitData>*)0x

TOFBarrelHits.cellID = 28992433719243100, 2817455770176

TOFBarrelHits.EDep = 0.000265, 0.000091, 0.000172, 0.0003

TOFBarrelHits.time = 4.053054, 14.312424, 4.063102, 4.028

TOFBarrelHits.pathLength = 0.615159, 0.067238, 0.583978, (

TOFBarrelHits.quality = 0, 1073741824, 0, 0

TOFBarrelHits.position.x = -53.5144, 637.172, -119.465, -63.

TOFBarrelHits.position.y = 637.215, -24.832, 623.996, 632.57

TOFBarrelHits.position.z = -1032.74, -7.37064, -1036.03, -10

TOFBarrelHits.momentum.x = -0.174216, 0.000106, -0.11352

TOFBarrelHits.momentum.y = 3.906600, 0.000118, 0.180725

TOFBarrelHits.momentum.z = -6.294468, 0.000010, -0.35606

TOFBarrelHits#0 = (vector<podio::ObjectID>*)0x483a1a0

TOFBarrelHits#0.index = 0, 0, 11, 10

TOFBarrelHits#0.collectionID = 1, 1, 1, 1

MCParticles = (vector<edm4hep::MCParticleData>*)0x48383a0

MCParticles.PDG = 11, 22, 22, 22, 22, 22, 22, 11, 11, 22, 11, -11, 22, 11, 11, 11, 22, 11, 22, 22

MCParticles.generatorStatus = 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0

MCParticles.simulatorStatus = 16777216, 1493172224, 1358954496, 1358954496, 1358954496, 1358954496, 1358954496, 1493172224, 1493172224, 1358954496, 1090519040, 1090519040, 1358954496, 1493172224, 1493172224, 1493172224, 1358954496, 1493172224, 1358954496, 1358954496

MCParticles.charge = -1.000000, 0.000000, 0.000000, 0.000000, 0.000000, 0.000000, 0.000000, -1.000000, -1.000000, 0.000000, -1.000000, 1.000000, 0.000000, -1.000000, -1.000000, -1.000000, 0.000000, -1.000000, 0.000000, 0.000000

MCParticles.time = 0.000000, 0.199721, 2.789866, 2.823105, 3.496814, 4.555848, 4.660157, 7.582368, 6.466424, 6.473745, 2.797891, 2.797891, 4.062873, 4.129636, 4.137900, 4.448593, 4.454385, 4.482966, 4.495162, 4.499579

MCParticles.mass = 0.000510999, 0, 0, 0, 0, 0, 0, 0.000510999, 0.000510999, 0, 0.000510999, 0.000510999, 0, 0.000510999, 0.000510999, 0.000510999, 0.000510999, 0, 0.000510999, 0, 0

MCParticles.vertex.x = 0, -3.81468, -42.1385, -42.4998, -49.123, -56.6974, -57.2298, -112.673, -227.236, -228.333, -52.8977, -52.8977, -119.465, -124.92, -125.622, -61.0513, -61, -60.7437, -60.6305, -60.5897

MCParticles.vertex.y = 0, 31.2885, 438.111, 443.343, 549.541, 716.937, 733.47, 390.766, 688.508, 686.551, 438.432, 438.432, 623.994, 632.722, 633.79, 700.094, 701.025, 705.629, 707.596, 708.308

MCParticles.vertex.z = 0, -50.9065, -711.173, -719.645, -891.317, -1160.98, -1187.52, -1486.82, -1537.9, -1538.03, -713.121, -713.121, -1036.03, -1053.2, -1055.32, -1132.84, -1134.31, -1141.53, -1144.61, -1145.73

MCParticles.endpoint.x = -43.7431, -52.8977, -55.7061, -71.6211, -64.6526, -60.6499, -55.6339, -114.097, -228.752, -918.054, -33.2575, -289.429, -179.066, -123.999, -114.256, -66.3573, -28.5205, -60.8964, 78.6462, -70.2267

MCParticles.endpoint.y = 926.163, 438.432, 841.654, 866.673, 829.648, 835.637, 857.75, 385.629, 685.627, -317.93, 871.297, 774.977, 820.931, 633.544, 636.151, 701.022, 884.34, 707.802, 934.962, 853.121

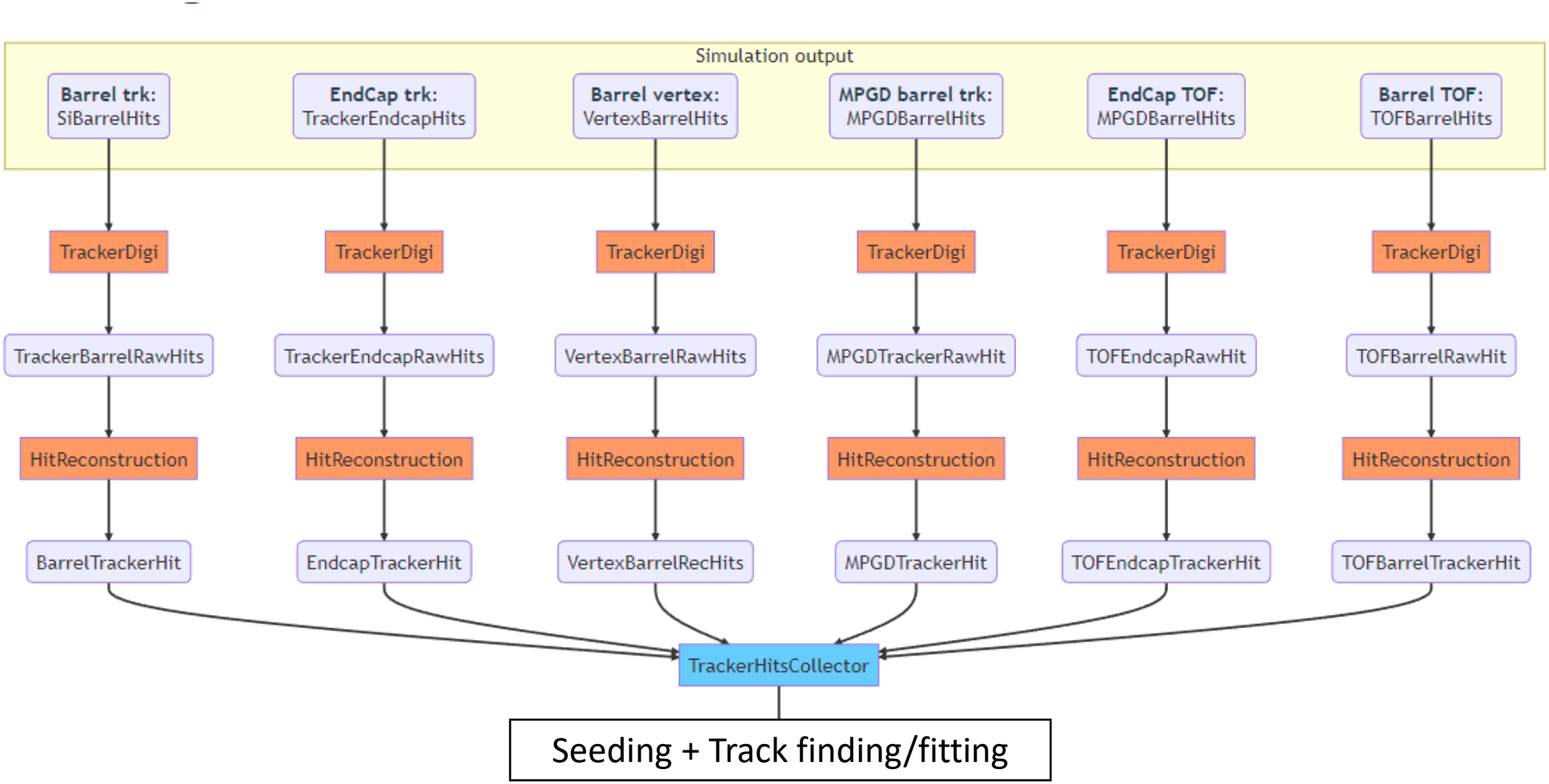
MCParticles.endpoint.z = -1461.45, -713.121, -1347.9, -1404.84, -1343.55, -1351.54, -1399.48, -1487.17, -1537.87, -1315.22, -1364.66, -1426.52, -1352.37, -1053.16, -1110.49, -1133.85, -1306.87, -1142.4, -1360.2, -1303.49

MCParticles.momentum.x = -0.607487, -0.109378, -0.000065, -0.006361, -0.002276, -0.000828, -0.000019, 0.000027, -0.002738, -0.000720, -0.083323, -0.025522, -0.000542, 0.000248, -0.001155, 0.001297, 0.003173, -0.001091, 0.000212, 0.000198

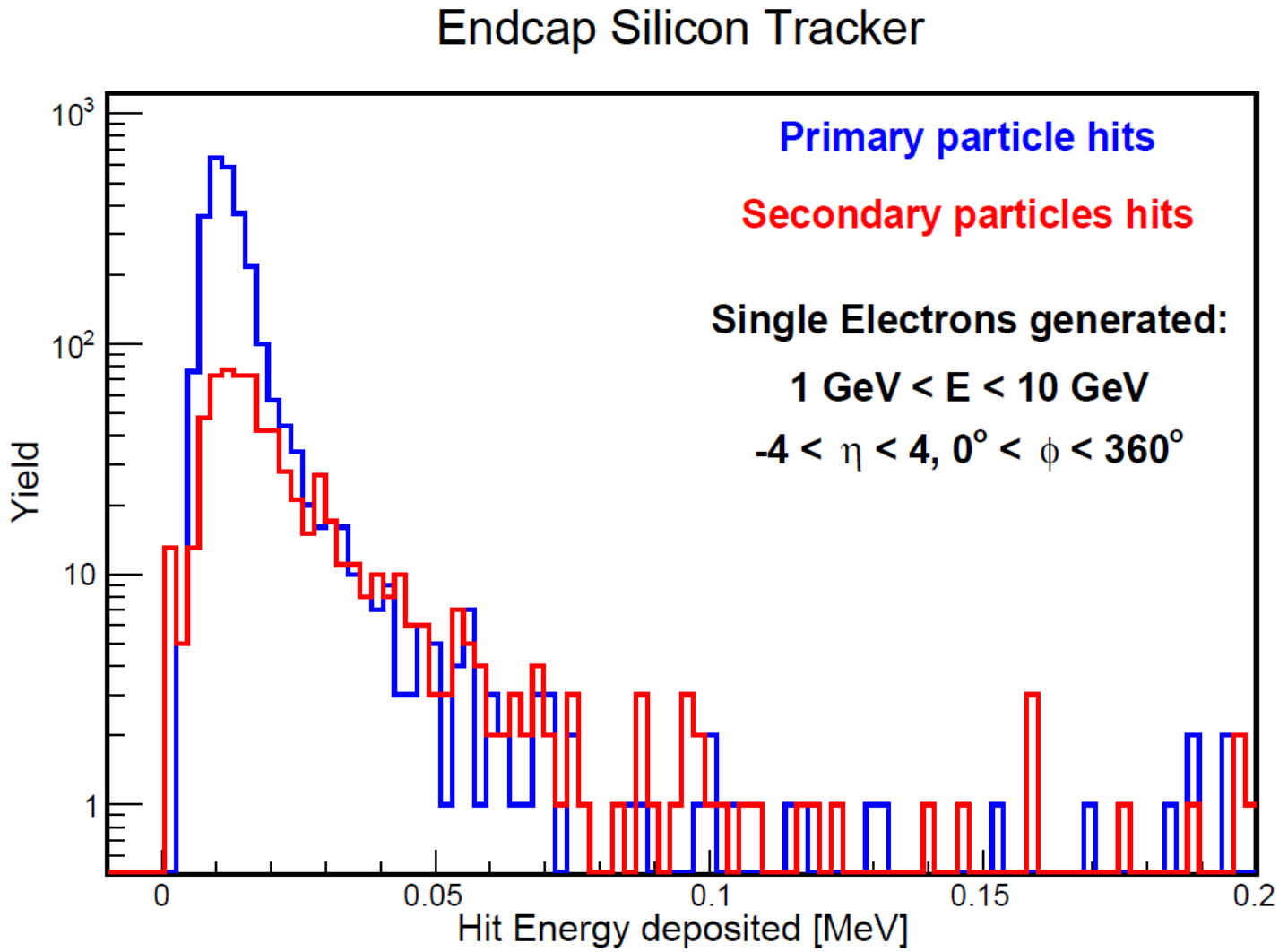
MCParticles.momentum.y = 4.916444, 0.907292, 0.000949, 0.092468, 0.041048, 0.024857, 0.000618, -0.004591, -0.003775, -0.001086, 0.687037, 0.220440, 0.000898, 0.001337, -0.000326, 0.001011, 0.058386, 0.001361, 0.003762, 0.003411

MCParticles.momentum.z = -8.000656, -1.475701, -0.001535, -0.149667, -0.066273, -0.039905, -0.000993, 0.000548, -0.001470, 0.000254, -1.117796, -0.357828, -0.001742, -0.000679, -0.002929, -0.001180, -0.091872, -0.001069, -0.005887, -0.005347

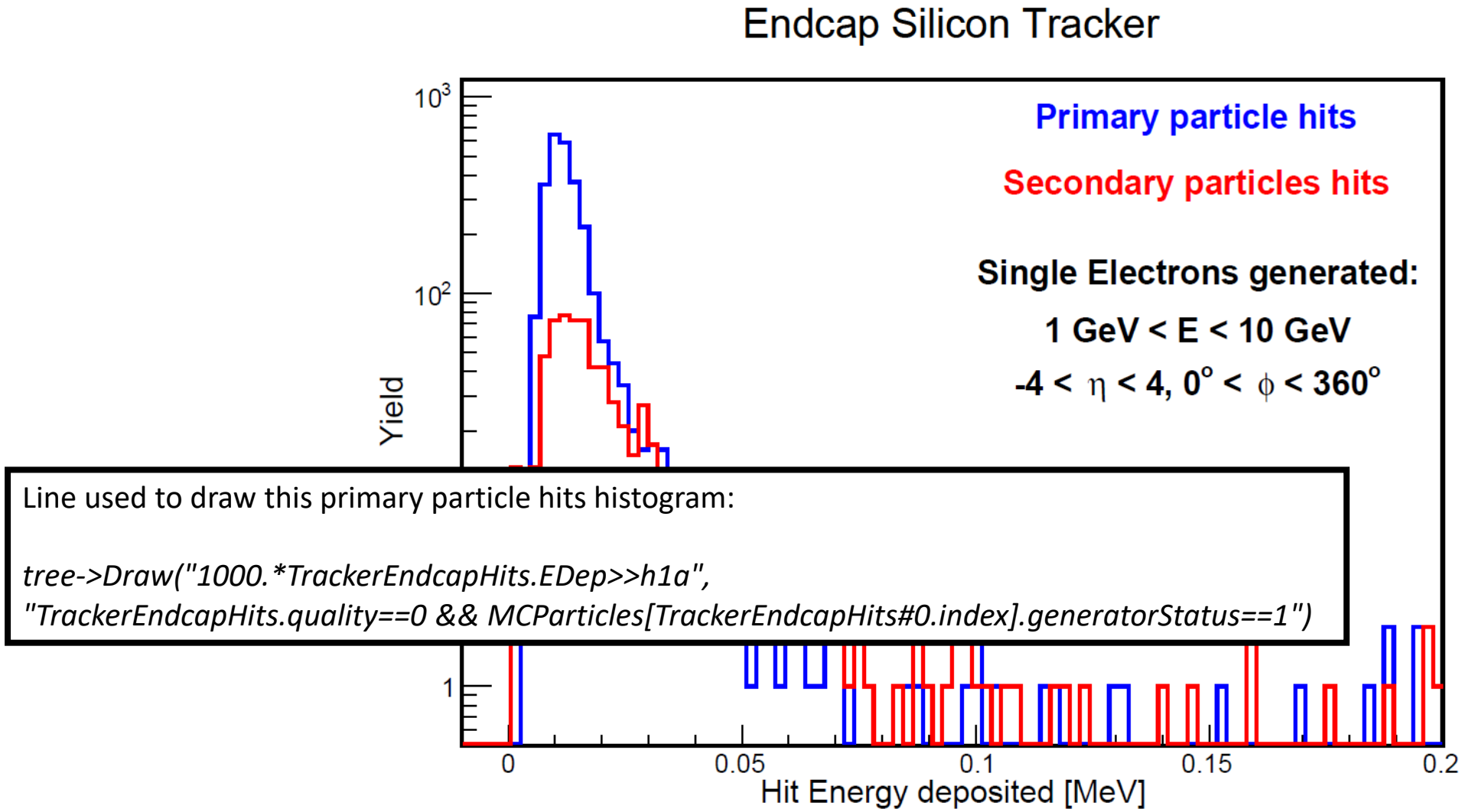
Tracking detectors in simulation



Hit energy deposition



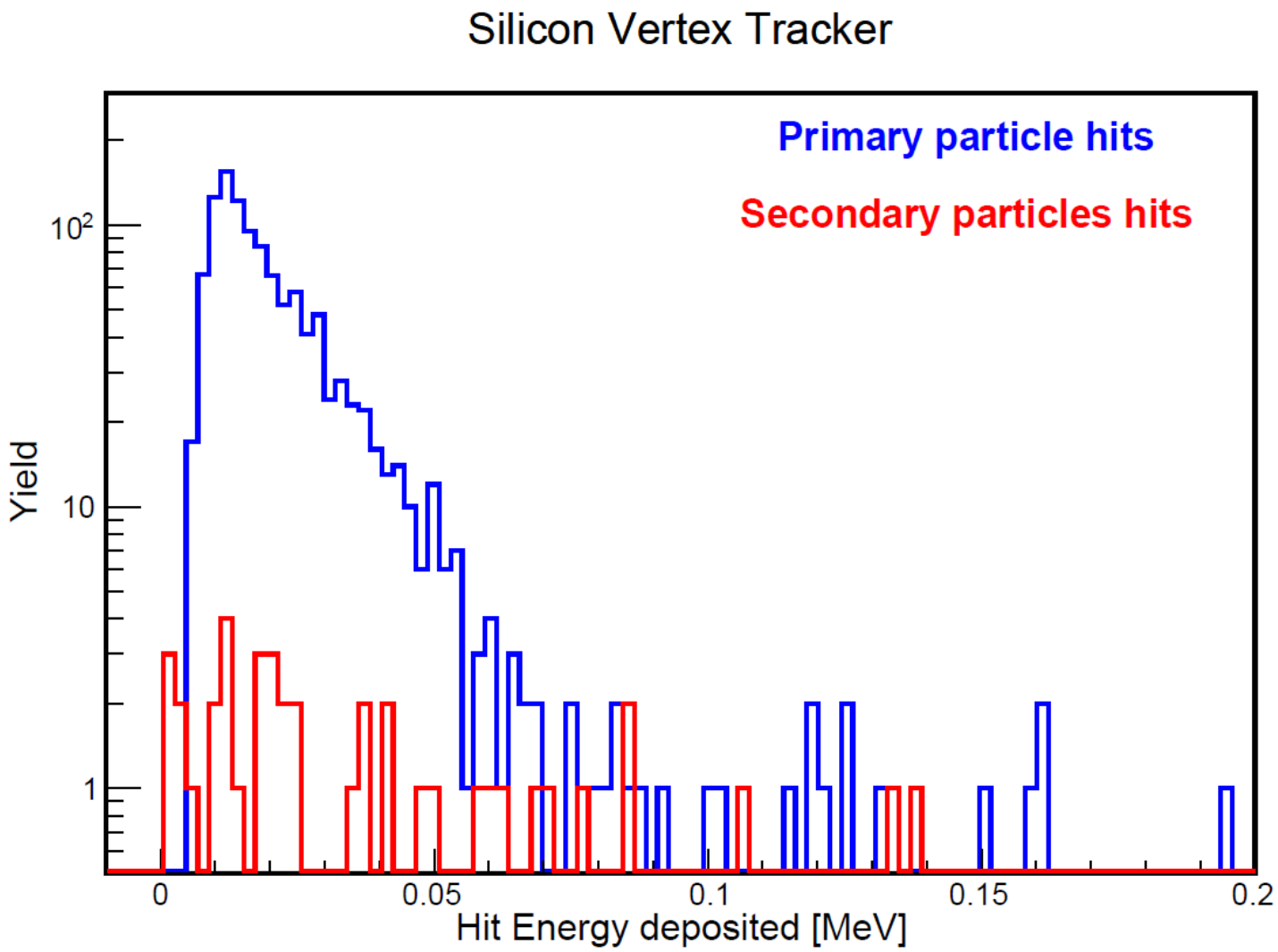
Hit energy deposition



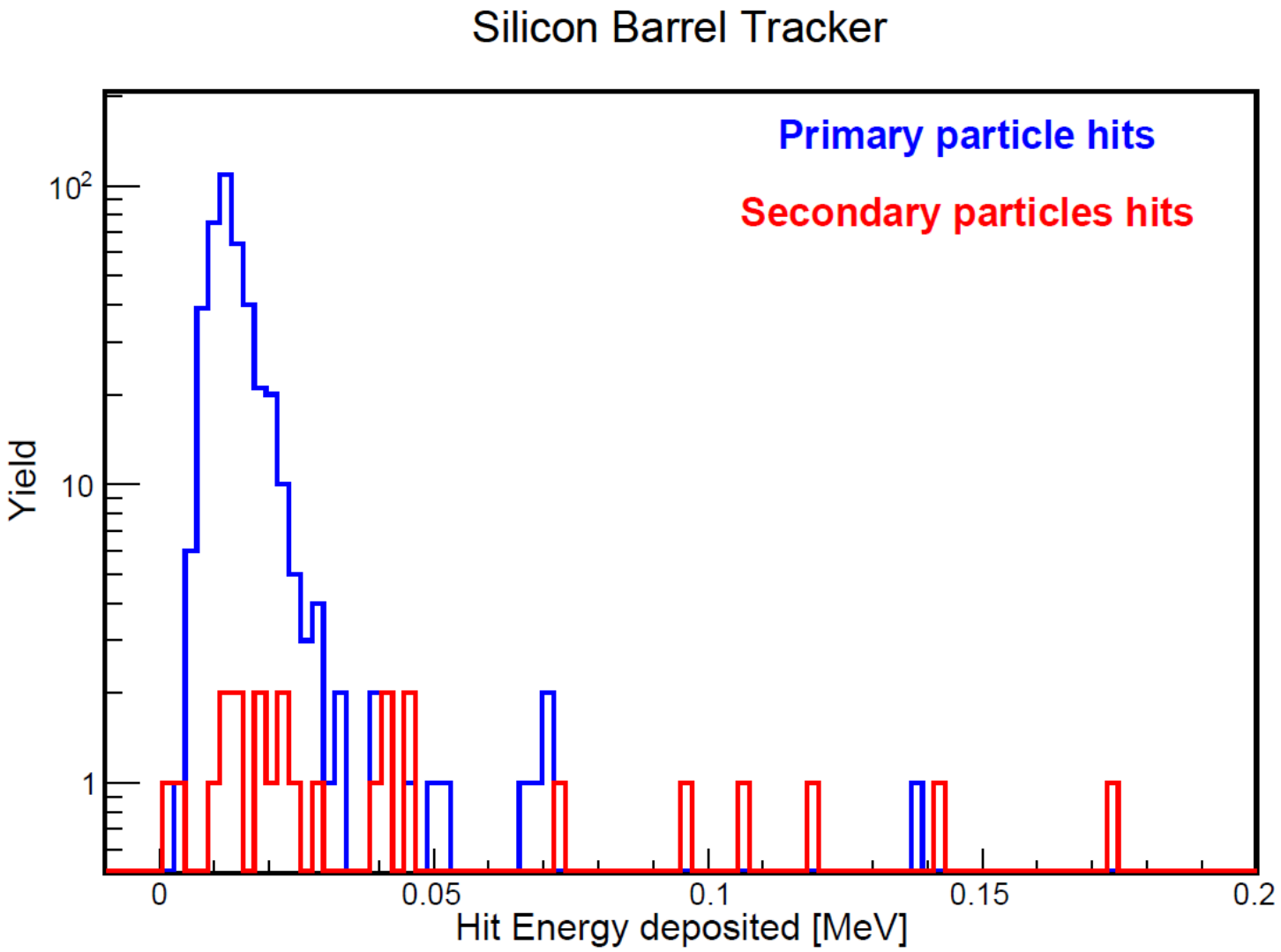
Line used to draw this primary particle hits histogram:

*tree->Draw("1000.*TrackerEndcapHits.EDep>>h1a",*
"TrackerEndcapHits.quality==0 && MCParticles[TrackerEndcapHits#0.index].generatorStatus==1")

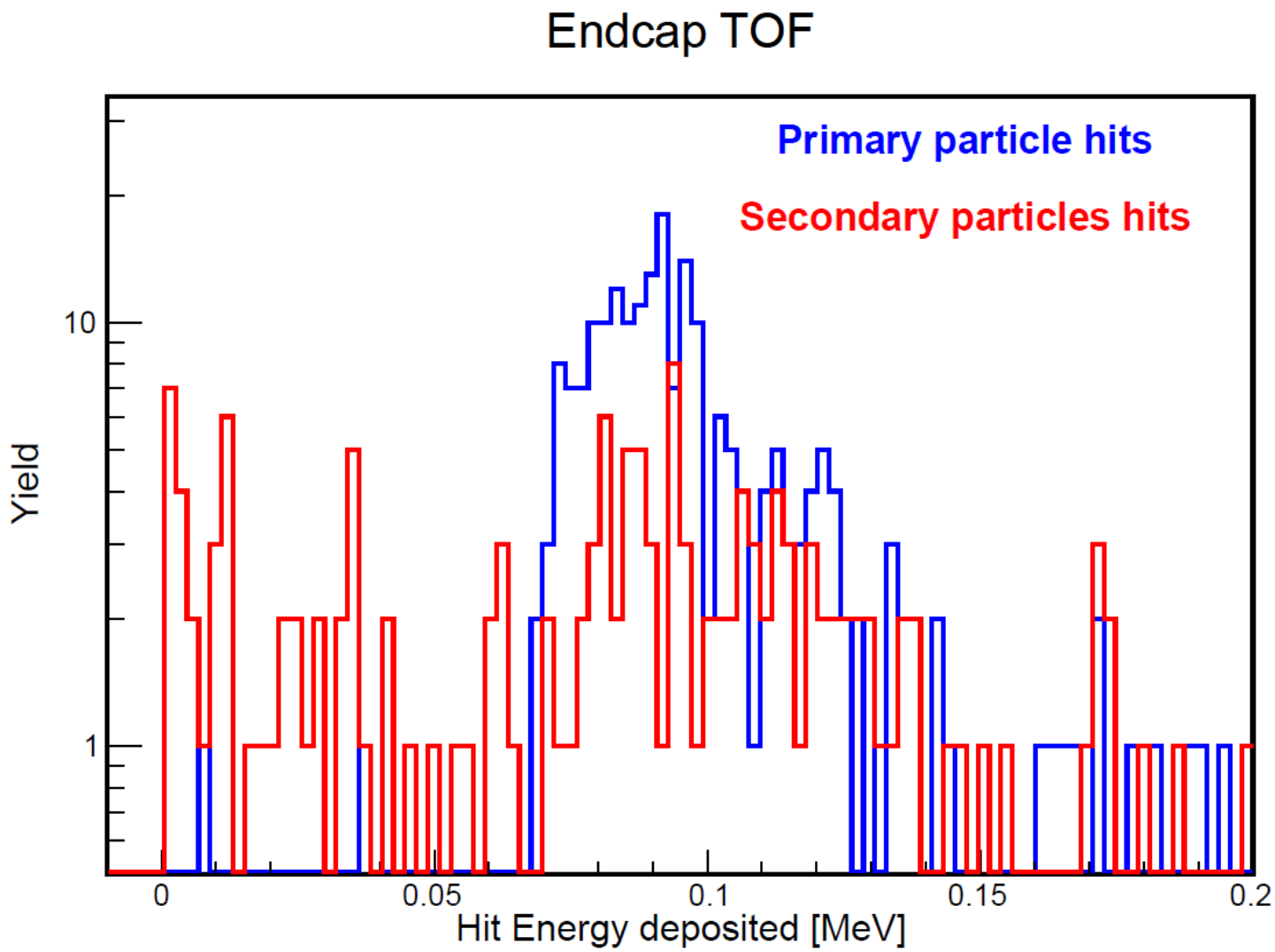
Hit energy deposition



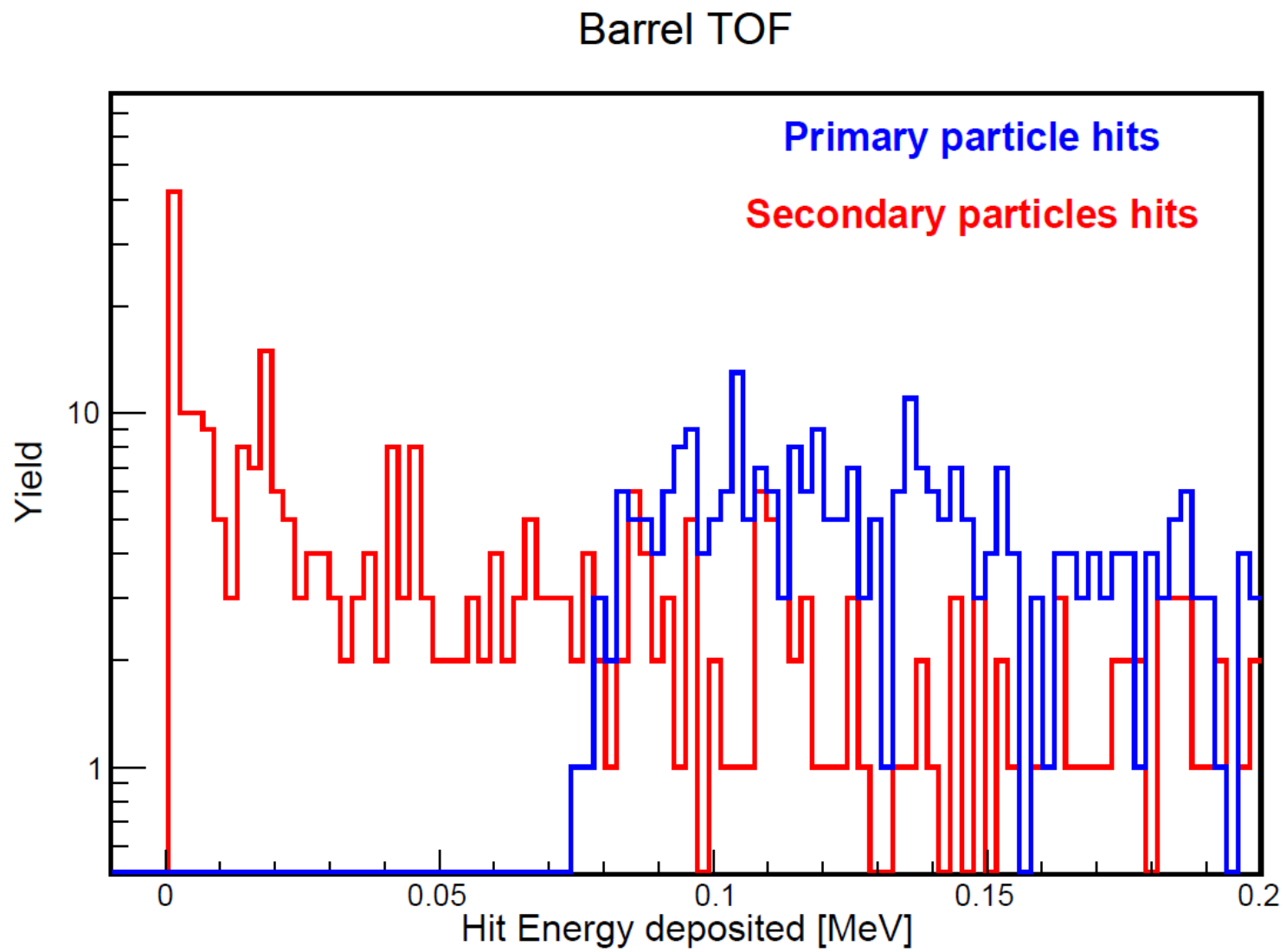
Hit energy deposition



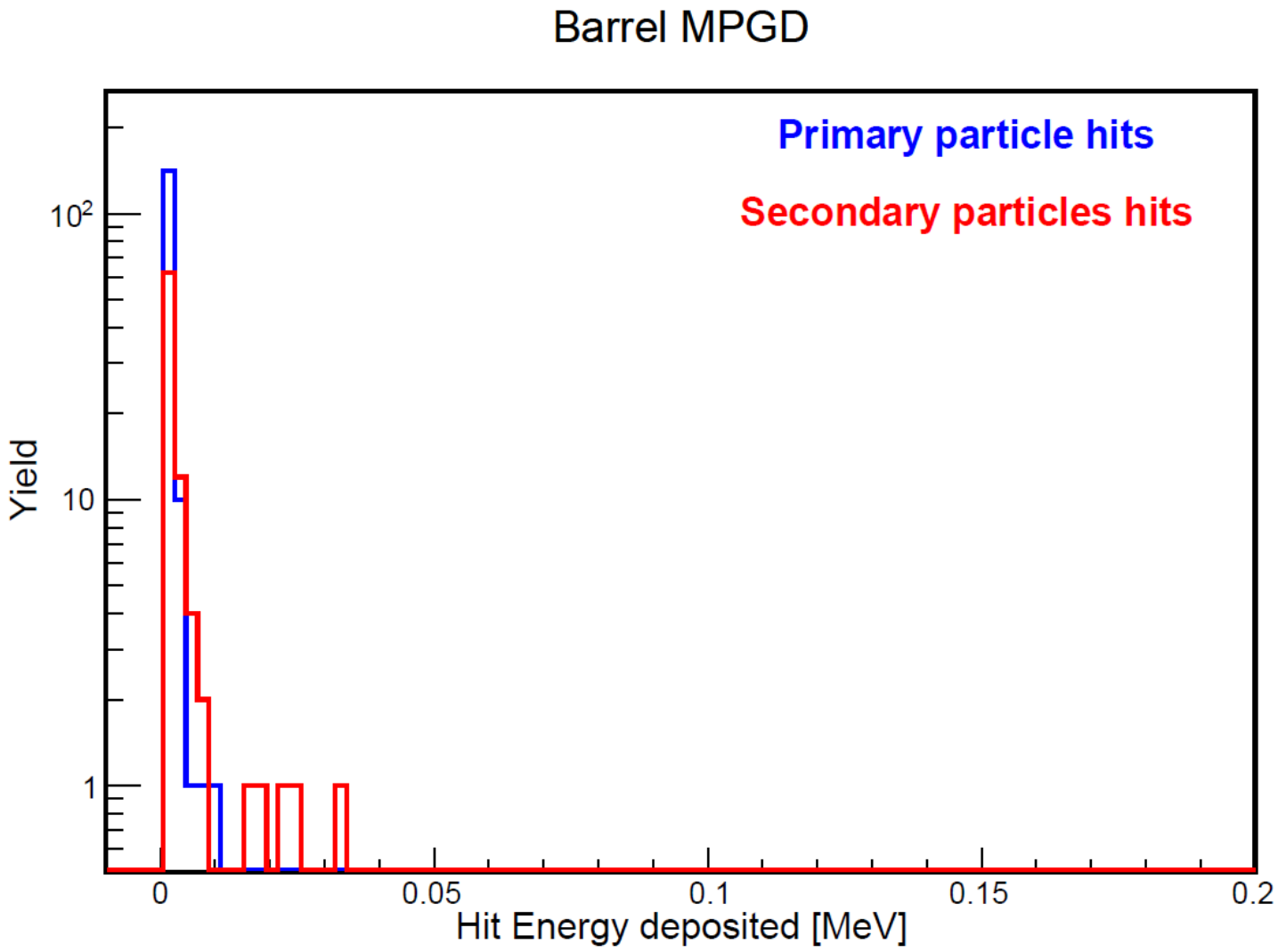
Hit energy deposition



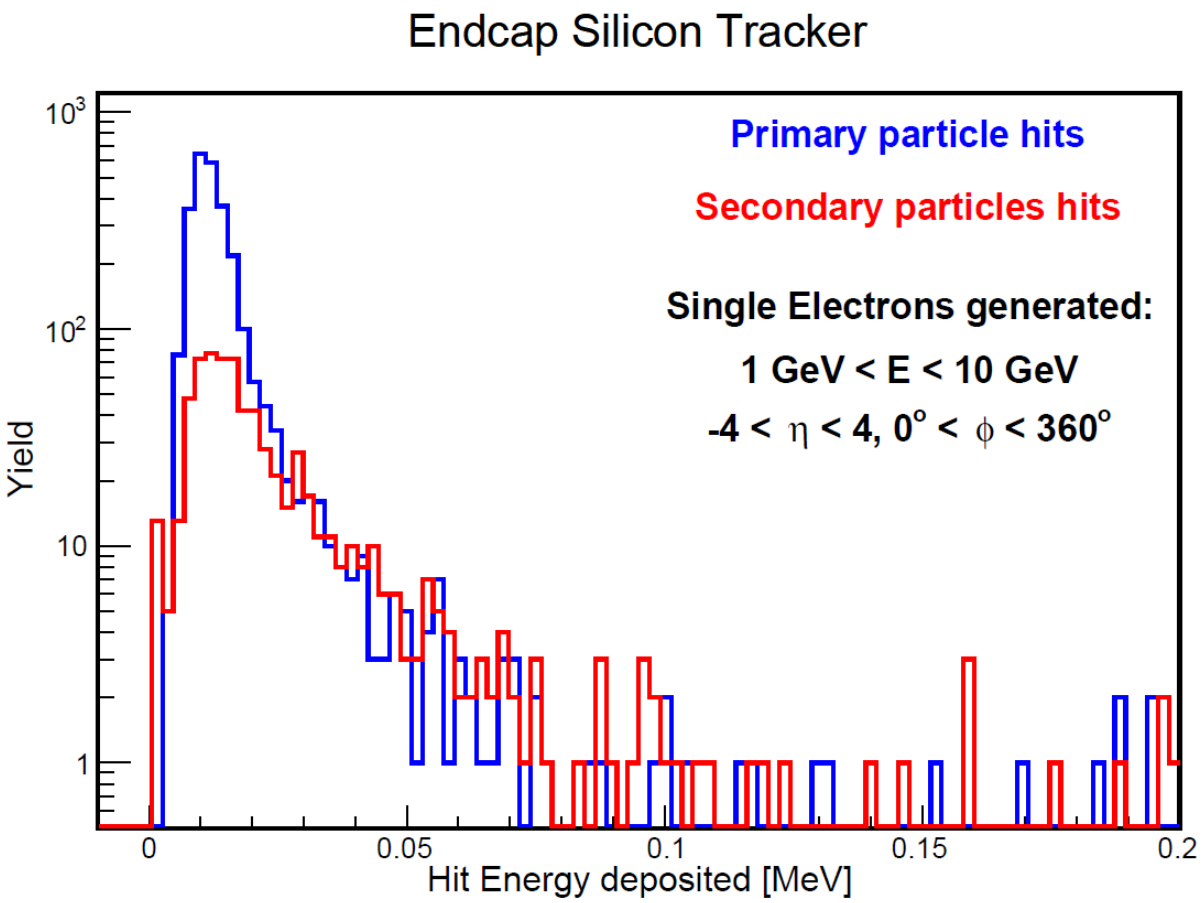
Hit energy deposition

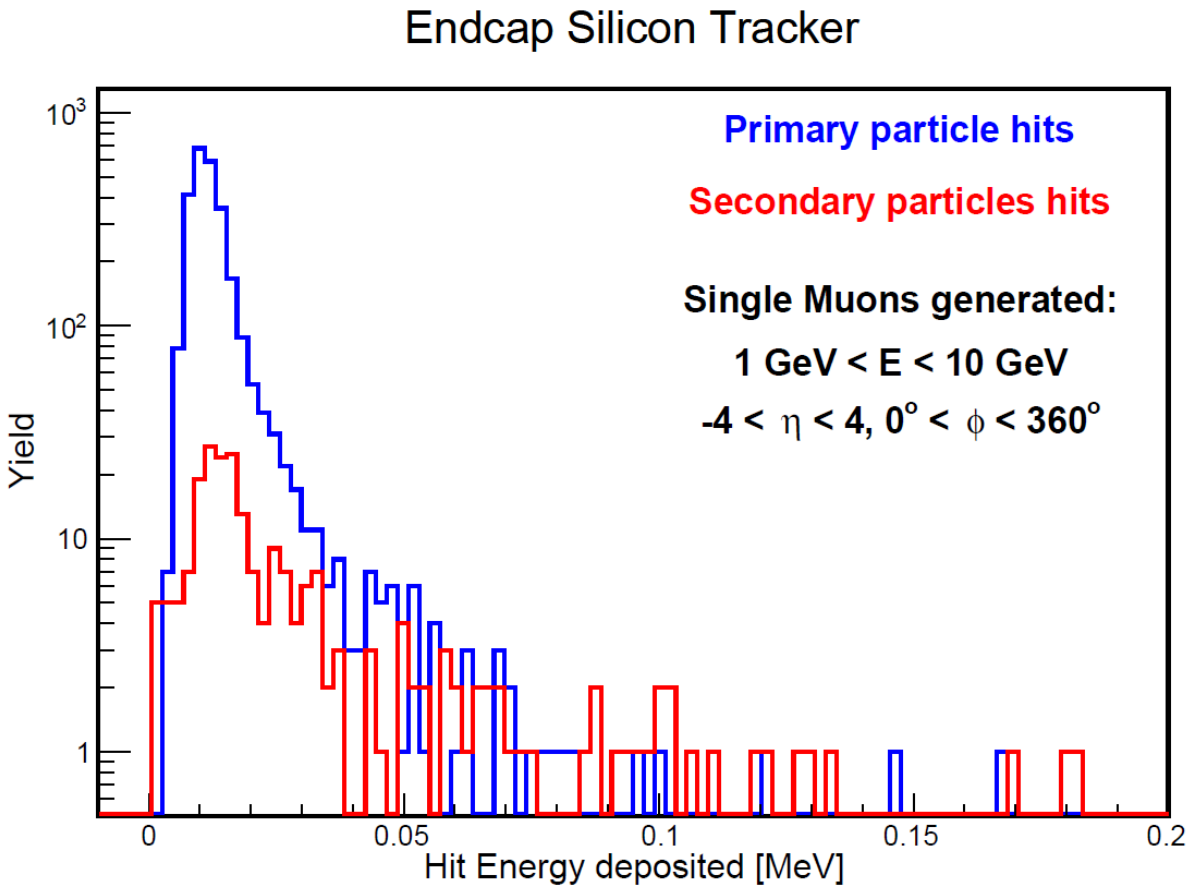


Hit energy deposition

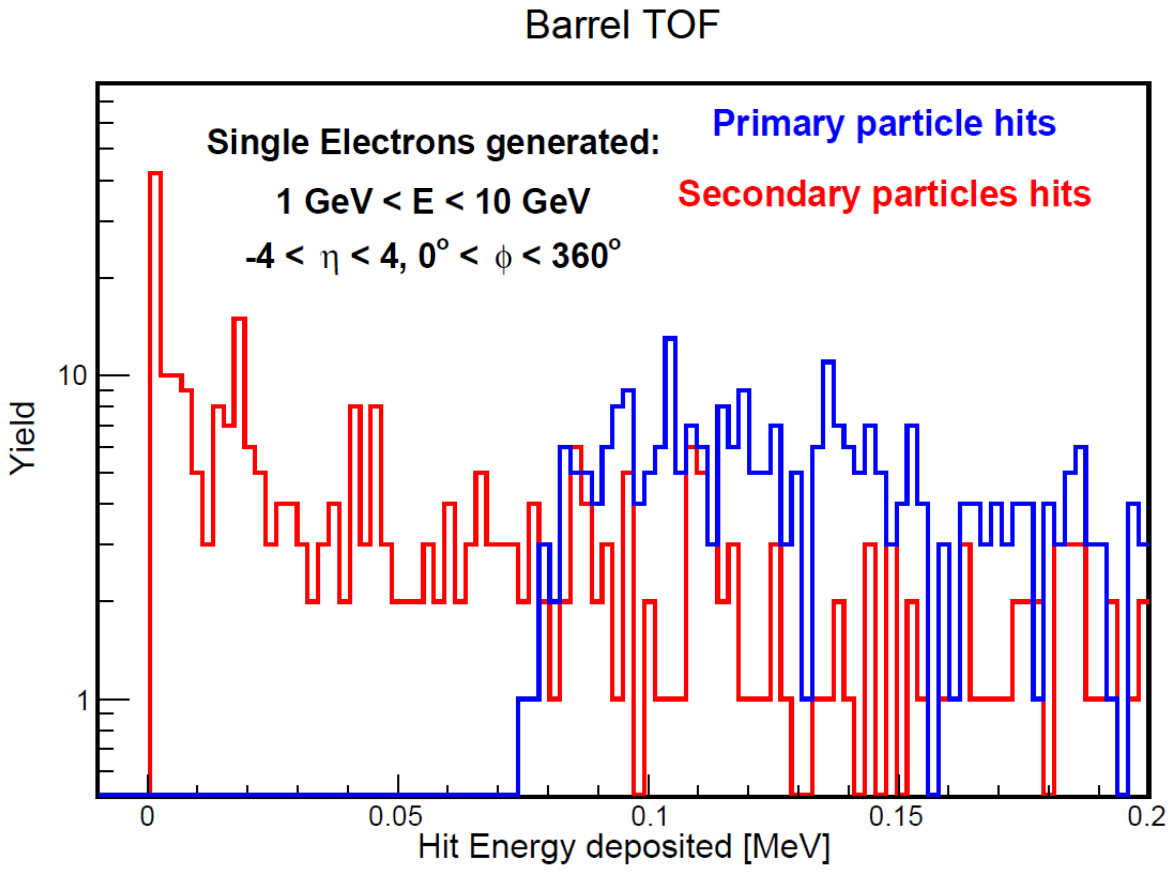


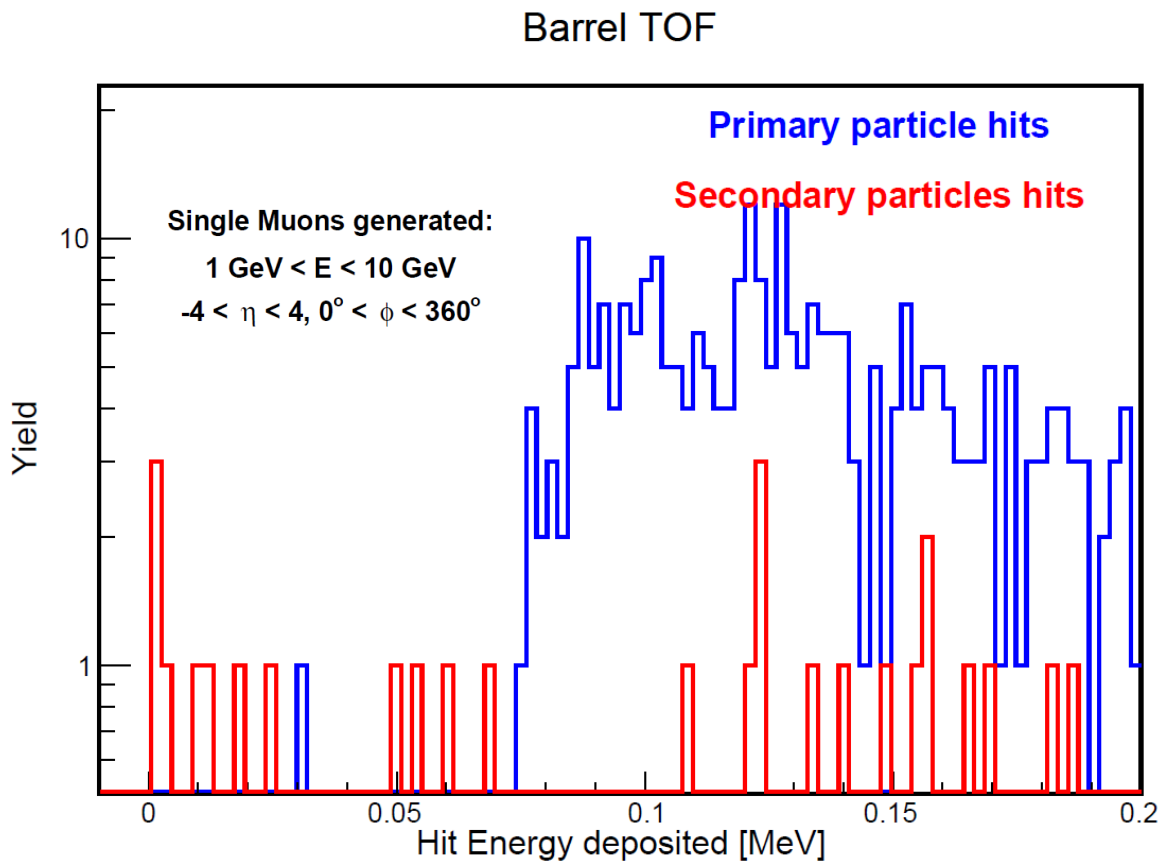
Hit energy deposition – comparison



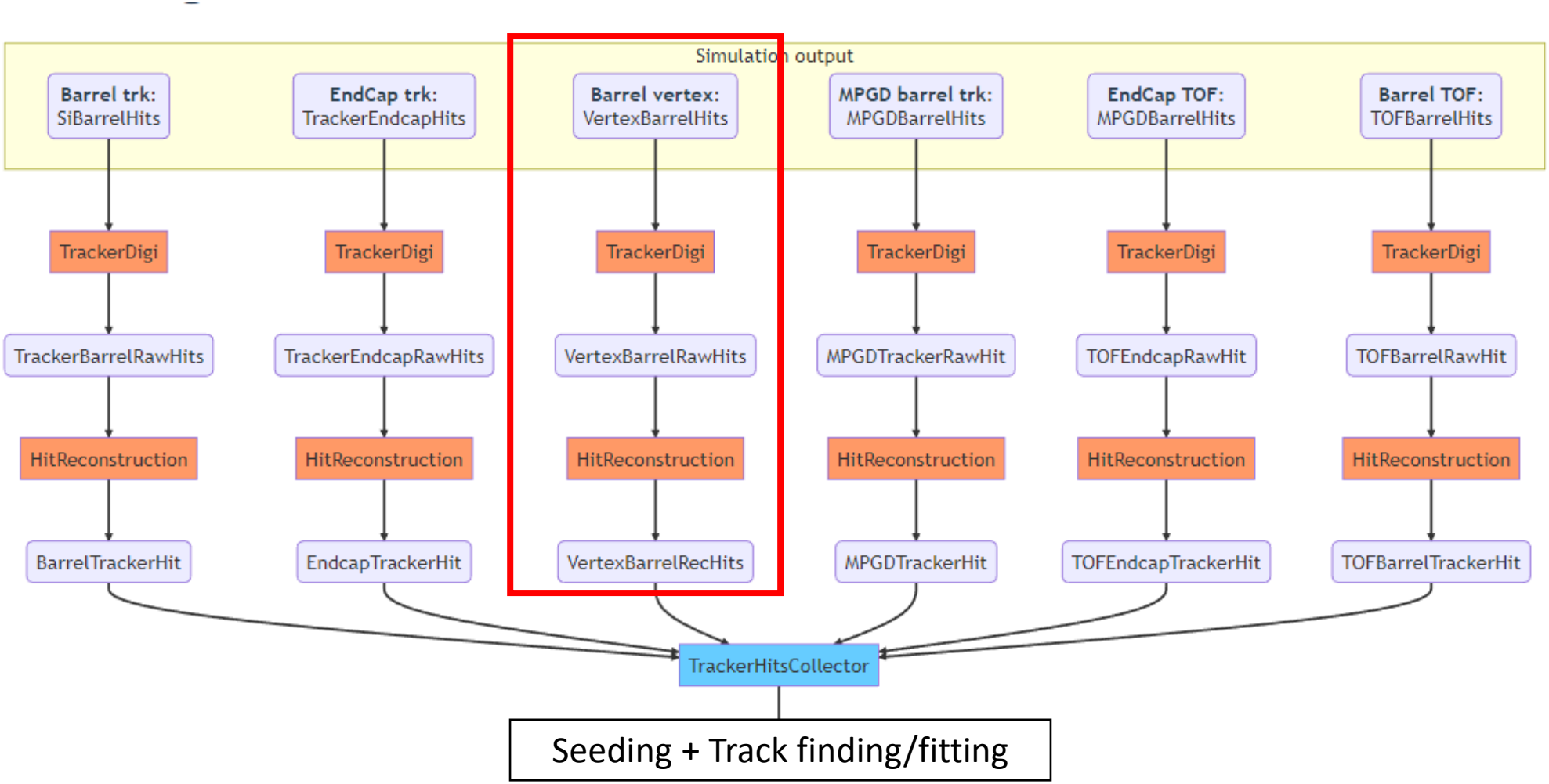


Hit energy deposition – comparison





Tracking detectors in simulation



‘Vertex Barrel’ digitization

```
extern "C" {
void InitPlugin(JApplication *app) {
    InitJANAPlugin(app);

    using namespace eicrecon;

    // Digitization
    app->Add(new JChainFactoryGeneratorT<SiliconTrackerDigi_factory>({"VertexBarrelHits"}, "BarrelVertexDigiHits"));

    // Convert raw digitized hits into hits with geometry info (ready for tracking)
    app->Add(new JChainFactoryGeneratorT<TrackerHitReconstruction_factory>({"BarrelVertexDigiHits"}, "SiBarrelVertexRecHits"));

}
```

https://github.com/eic/EICrecon/blob/main/src/detectors/BVTX/BVTX.cc

‘Vertex Barrel’ digitization – factories call algorithms

https://github.com/eic/EICrecon/blob/main/src/algorithms/digi/SiliconTrackerDigiConfig.h

```
namespace eicrecon {

    struct SiliconTrackerDigiConfig {
        double threshold  = 0;
        double timeResolution = 8;   /// TODO 8 of what units??? Same TODO in juggler. Probably [ns]
    };

} // eicrecon
```

https://github.com/eic/EICrecon/blob/main/src/algorithms/digi/SiliconTrackerDigi.cc

```
for (const auto sim_hit : sim_hits) {

    // time smearing
    double time_smearing = m_gauss();
    double result_time = sim_hit->getTime() + time_smearing;
    auto hit_time_stamp = (std::int32_t) (result_time * 1e3);

    m_log->debug("--------------------");
    m_log->debug("Hit cellID   = {}", sim_hit->getCellID());
    m_log->debug("   position  = ({:.2f}, {:.2f}, {:.2f})", sim_hit->getPosition().x, sim_hit->getPosition().y, sim_h
    m_log->debug("   xy_radius = {:.2f}", std::hypot(sim_hit->getPosition().x, sim_hit->getPosition().y));
    m_log->debug("   momentum  = ({:.2f}, {:.2f}, {:.2f})", sim_hit->getMomentum().x, sim_hit->getMomentum().y, sim_h
    m_log->debug("   edep = {:.2f}", sim_hit->getEDep());
    m_log->debug("   time = {:.4f}[ns]", sim_hit->getTime());
    m_log->debug("   particle time = {}[ns]", sim_hit->getMCParticle().getTime());
    m_log->debug("   time smearing: {:.4f}, resulting time = {:.4f} [ns]", time_smearing, result_time);
    m_log->debug("   hit_time_stamp: {} [~ps]", hit_time_stamp);


    double edep = sim_hit->getEDep();
    if (edep * units::keV < m_cfg.threshold) {
        m_log->debug("  edep is below threshold of {:.2f} [keV]", m_cfg.threshold / units::keV);
        continue;
    }
```

```
if (cell_hit_map.count(sim_hit->getCellID()) == 0) {
    // This cell doesn't have hits
    cell_hit_map[sim_hit->getCellID()] = {
            (std::int32_t) std::llround(sim_hit->getEDep() * 1e6),
            hit_time_stamp}; // ns->ps
} else {
    // There is previous values in the cell
    RawHit &prev_hit = cell_hit_map[sim_hit->getCellID()];
    m_log->debug("  Hit already exists in cell ID={}, prev. hit time: {}", sim_hit->getCellID(), prev_hit.time_stamp);
    prev_hit.time_stamp = std::min(hit_time_stamp, prev_hit.time_stamp);  // keep earliest time for hit
    prev_hit.charge += (std::int32_t) std::llround(sim_hit->getEDep() * 1e6);
}
```

‘Vertex Barrel’ digitization – factories call algorithms

```
namespace eicrecon {
    struct TrackerHitReconstructionConfig {
        float time_resolution = 10;
    };
}
```

https://github.com/eic/EICrecon/blob/main/src/algorithms/tracking/TrackerHitReconstructionConfig.h

```
return new edm4eic::TrackerHit(
        raw_hit->getCellID(), // Raw DD4hep cell ID
    {static_cast<float>(pos.x() / mm), static_cast<float>(pos.y() / mm), static_cast<float>(pos.z() / mm)}, // mm
    {get_variance(dim[0] / mm), get_variance(dim[1] / mm), // variance (see note above)
     std::size(dim) > 2 ? get_variance(dim[2] / mm) : 0.},
       static_cast<float>((double)(raw_hit->getTimeStamp()) / 1000.0), // ns
    m_cfg.time_resolution,                              // in ns
    static_cast<float>(raw_hit->getCharge() / 1.0e6),   // Collected energy (GeV)
    0.0F);                                          // Error on the energy
```

https://github.com/eic/EICrecon/blob/main/src/algorithms/tracking/TrackerHitReconstruction.cc

Tracking detectors in simulation