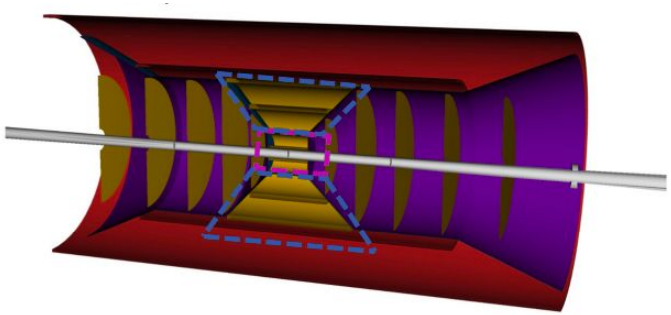
Issues with Noise Implementation in the ePIC Silicon Tracker Layers

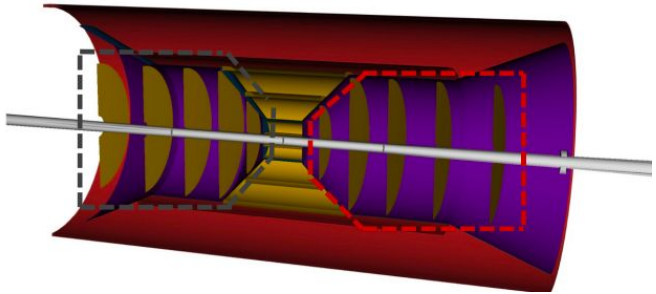
Current Estimation of Noise Hit Count

Sampled fake-hit rate: **FHR < 5 x 10^{-7} per event per pixel**
Fake hits/event/collection: **FHR x total pixels**

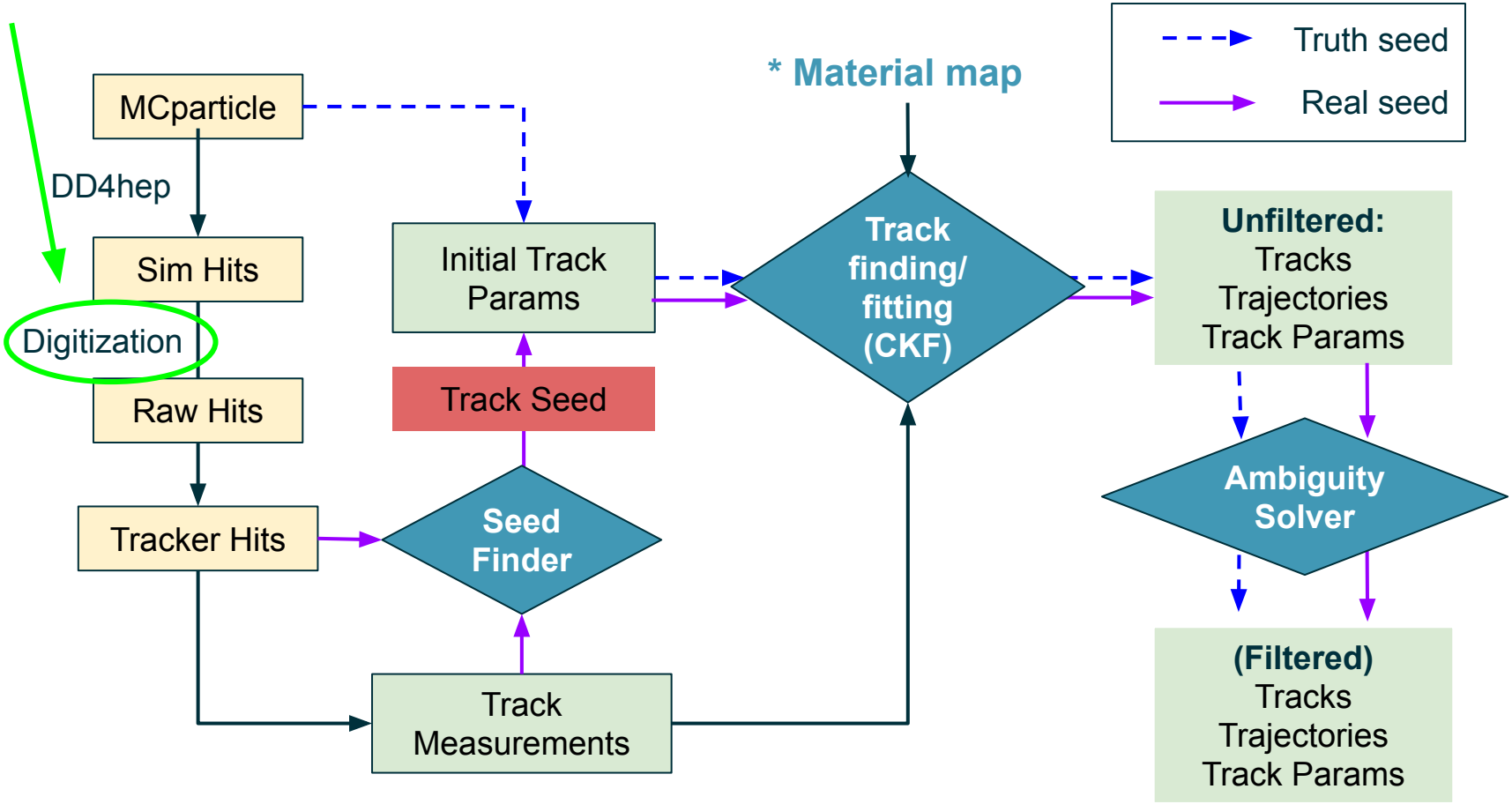
Pixels sizes: **20x20µm²**

	Inner Barrel	Outer Barrel	Endcaps
Est. total pixels	8.65E+08	7.83E+09	1.18E+10
Fake hits/event	4.33E+02	3.92E+03	5.91E+03





Noise Implementation



Step 1: Set up the workflow with pre-generated cell ID

1. SiliconTrackerDigi.cc

```
std::vector<std::uint64_t> disk_noisehits = {861596784923877709,…
for (const auto& disk_noisehit : disk_noisehits) {…

std::vector<std::uint64_t> btrk_noisehits = {12628316263719227,…
for (const auto& btrk_noisehit : btrk_noisehits) {…

std::vector<std::uint64_t> bvtx_noisehits = {18301502869779853855,…
for (const auto& bvtx_noisehit : bvtx_noisehits) {…
```

2. SiliconTrackerDigiConfig.h

```
bool bvtxnoise = false;
bool btrknoise = false;
bool disknoise = false;
```

3. SiliconTrackerDigi_factory.h

```
ParameterRef<bool> m_bvtxnoise {this, "bvtxnoise", config().bvtxnoise};
ParameterRef<bool> m_btrknoise {this, "btrknoise", config().btrknoise};
ParameterRef<bool> m_disknoise {this, "disknoise", config().disknoise};
```

4. BVTX, BTRK, ECTRK.cc

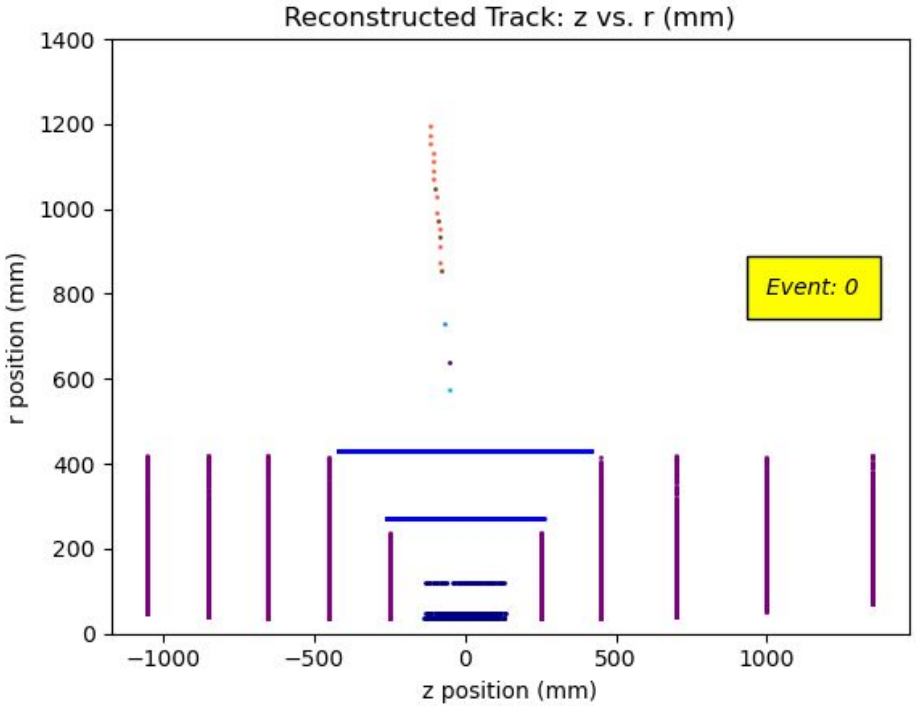
```
.btrknoise = true,
.bvtxnoise = true,
.disknoise = true,
```

Inside the for-loop:

1. Add noise cellID's into the cellhit map for detectors with **noise==true** (BVTX, BTRK, ECTRK)
2. Define energy to be anything above the threshold
3. Define a random timestamp

```
for (const auto& bvtx_noisehit : bvtx_noisehits) {

        // time smearing
        double time_smearing = m_gauss();
        double result_time = 1 + time_smearing; //replaced sim_hit.getTime() with 1, a random number
        auto hit_time_stamp = (std::int32_t) (result_time * 1e3); //do I have to change the name of hit_time_stamp be
        //no, if defined under different blocks, they don't clash.

        if (m_cfg.bvtxnoise == true) { //add another if statement
        //std::cout << "it's a noise hit!" << std::endl;

            if (cell_hit_map.count(bvtx_noisehit) == 0) { //replaced sim_hit.getCellID() with noise_hits[noise_hit] t
                // This cell doesn't have hits
                cell_hit_map[bvtx_noisehit] = {
                    bvtx_noisehit,
                    (std::int32_t) std::llround(5.4 * 1e6), //*1e6 to convert from KeV it to be GeV
                    hit_time_stamp  // ns->ps
                };
            } else {
                // There is previous values in the cell
                auto& hit = cell_hit_map[bvtx_noisehit];
                debug("  Hit already exists in cell ID={}, prev. hit time: {}", bvtx_noisehit, hit.getTimeStamp());

                // keep earliest time for hit
                auto time_stamp = hit.getTimeStamp(); //where is getTimeStamp defined?
                hit.setTimeStamp(std::min(hit_time_stamp, hit.getTimeStamp()));

                // sum deposited energy
                auto charge = hit.getCharge();
                hit.setCharge(charge + (std::int32_t) std::llround(5.4 * 1e6));
            }
        }
}
```

Successful reconstruction of manually inputted cellID's



Description: Reconstructed hit position plot for one single-muon event. Includes manually inputted SVT hits, whose cellID's were copied from a separate reconstruction file.

Step 2: Generate random 64-bit Cell ID's efficiently

Inner Barrels: system:8,layer:4,module:12,sensor:2,x:32:-16,y:-16

Outer Barrels: system:8,layer:4,module:12,sensor:2,x:32:-12,y:-20

Endcap disks: system:8,layer:4,module:12,sensor:2,x:32:-16,z:-16 *(from the detector xml files)*

Collect. name	sys_id	layer	module	sensor	*seg_x	*seg_y/z	# est. noise hits
IB	31	1,2,4	1-128	1	***~146*	*~13500*	433
OB	59, 60	1	1-44, 1-69	1	*ongoing study*	*ongoing study*	3920
Disks	68-70, 77-79	1	1-36	1	*ongoing study*	*ongoing study*	5910

*ATM, we know the segment ranges for IB. Included are number of pixels
**stave width translates to at most 146 pixels (depends on layer), and they are stored in 32-bits

Would like to gather input:

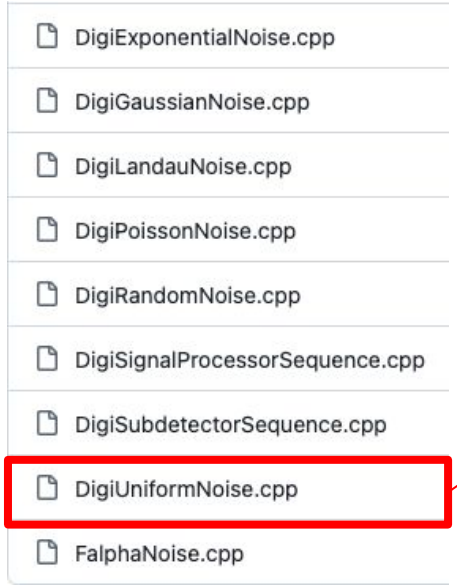
We are trying to find an efficient way to provide these information to the digi file and generate noise hits that are uniformly distributed across the SVT layers. For loop is possible, but a more automated process is desirable.

Incorporating noise hits is also important for other detectors (i.e. calorimeters), so a unified solution in that sense would be ideal

Noise Folder in DD4hep

Link:https://github.com/eic/DD4hep/tree/4234279b462b521d215ace43c36b920e8c1fe719/DDDigi/src/noise

Git Location: DD4hep/DDDigi/src/noise




```cpp
// Framework include files
#include <DD4hep/InstanceCount.h>
#include <DDDigi/DigiRandomGenerator.h>
#include <DDDigi/noise/DigiUniformNoise.h>

using namespace dd4hep::digi;

/// Standard constructor
DigiUniformNoise::DigiUniformNoise(const DigiKernel& krnl, const std::string& nam)
  : DigiSignalProcessor(krnl, nam)
{
  declareProperty("minimum", m_min);
  declareProperty("maximum", m_max);
  InstanceCount::increment(this);
}

/// Default destructor
DigiUniformNoise::~DigiUniformNoise() {
  InstanceCount::decrement(this);
}

/// Callback to read event uniformnoise
double DigiUniformNoise::operator()(DigiCellContext& context)  const  {
  return context.context.randomGenerator().uniform(m_min,m_max);
}
```

Backup

Step 2: Generate random 64-bit Cell ID's efficiently

Inner Barrels: system:8,layer:4,module:12,sensor:2,x:32:-16,y:-16

Outer Barrels: system:8,layer:4,module:12,sensor:2,x:32:-12,y:-20

Endcap disks: system:8,layer:4,module:12,sensor:2,x:32:-16,z:-16 *(from the detector xml files)*

Collect. name	sys_id	layer	module	sensor	seg_x (L**0**,**1**,**2**,**3**,**4**)	seg_y/z	# est. noise hits
IB	31	1,2,4	1-128	1	**(0,43) or (65492, 65535)** **(0,57) or (65478, 65535)** **(0,146) or (65386, 65535)**	(0,6749) or (58786,65535)	433
OB	59, 60	1	1-44, 1-69	1	*ongoing study*	*ongoing study*	3920
Disks	68-70, 77-79	1	1-36	1	*ongoing study*	*ongoing study*	5910

Segment_x Calculations

Credit: Barak Schmookler

1. Calculate # pixels along xy of staves by dividing widths of staves by 20um

```
VertexBarrelStave1_width = 2*(36*1000 um)*tan(180 * (pi/180) / 128) = 1767.500791842632 um   = 88.375 pixels
VertexBarrelStave2_width = 2*(48*1000 um)*tan(180 * (pi/180) / 128) = 2356.6677224568425 um  = 117.833 pixels
VertexBarrelStave2_width = 2*(120*1000 um)*tan(180 * (pi/180) / 128) = 5891.6693061421065 um = 294.58 pixels
```

2. Divide (1) by 2 because starting segmentation value jump from 0 to 65535 (smallest->largest 64bit #) at middle of each stave

Segment_y Calculations

```
<constant name="VertexBarrel_length"                    value="270.0*mm"/>
```

1. Calculate # pixels along z: 270000um/20um = 13500 pixels
2. Divide (2) by 2 because segmentation values jump because starting segmentation value jump from 0 to 65535 (smallest->largest 64bit #) at z=0

Comparing segment y vs. global z

```
---------------------
Z bit value = 0
Current cell ID = 17289503
Current cell Position : {x , y , z} = {35.308270 , -7.023252 , 0.000000} mm
Current cell Position : {r , z} = {36.000000 , 0.000000} mm
Current cell ID converted from Position = 17289503
---------------------

Warning in <TGeoMatrix::dtor>: Registered matrix component0_placement was removed
---------------------
Z bit value = 1
Current cell ID = 281474994000159
Current cell Position : {x , y , z} = {35.308270 , -7.023252 , -0.020000} mm
Current cell Position : {r , z} = {36.000000 , -0.020000} mm
Current cell ID converted from Position = 281474994000159
---------------------
```

Credit: Barak Schmookler

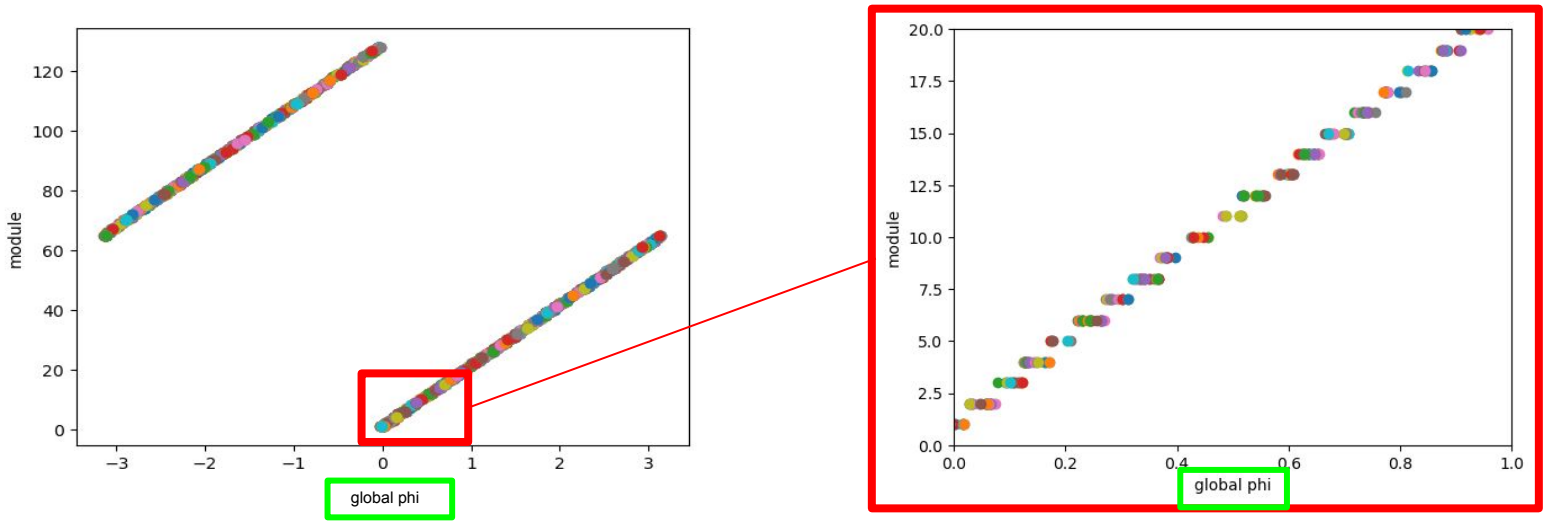
Comparing segment y vs. global z

```
Warning in <TGeoMatrix::dtor>: Registered matrix component0_placement was removed
---------------------
Z bit value = 65534
Current cell ID = 18446181123773419807
Current cell Position : {x , y , z} = {35.308270 , -7.023252 , 0.040000} mm
Current cell Position : {r , z} = {36.000000 , 0.040000} mm
Current cell ID converted from Position = 18446181123773419807
---------------------

Warning in <TGeoMatrix::dtor>: Registered matrix component0_placement was removed
---------------------
Z bit value = 65535
Current cell ID = 18446462598750130463
Current cell Position : {x , y , z} = {35.308270 , -7.023252 , 0.020000} mm
Current cell Position : {r , z} = {36.000000 , 0.020000} mm
Current cell ID converted from Position = 18446462598750130463
```

Credit: Barak Schmookler

Example Plots for Inner Barrels:

global phi vs. module



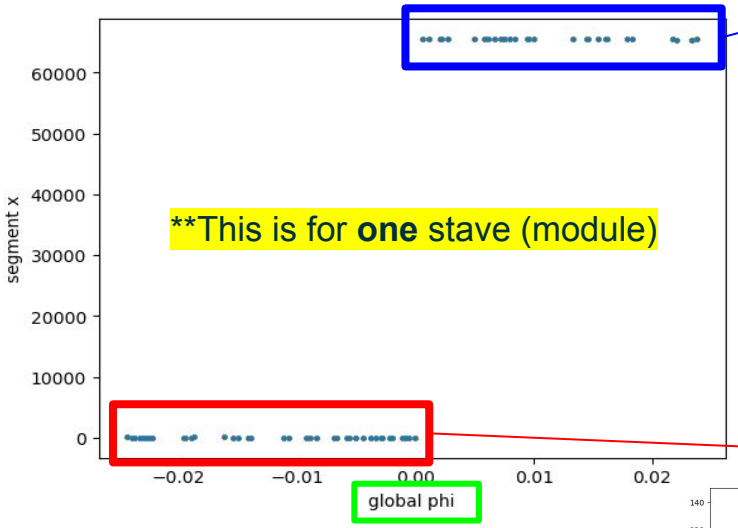
global_phi = np.arctan2(y,x)

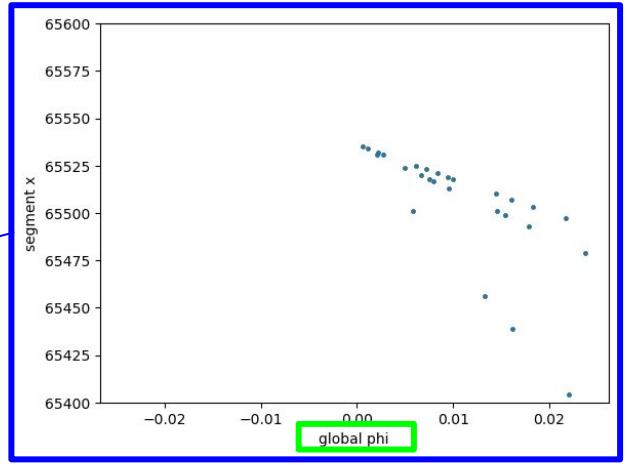
- y=SiBarrelVertxRecHits.position.y
- x= SiBarrelVertxRecHits.position.x

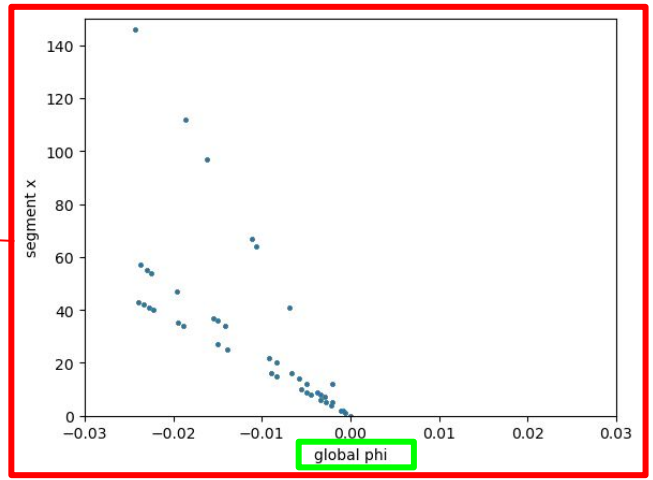
**Each point are actual hits from single-particle simulation rather than noise hits. The values on the y-axis of both plots are extracted from bitwise operations on the cellID variable, and the x-axis as defined in the green box. For the sake of runtime, plots from here include 2000 random events from the 10000 generated events.*

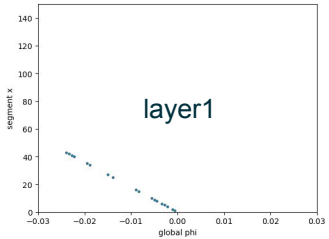
Example Plots for Inner Barrels:

global phi vs. segment x







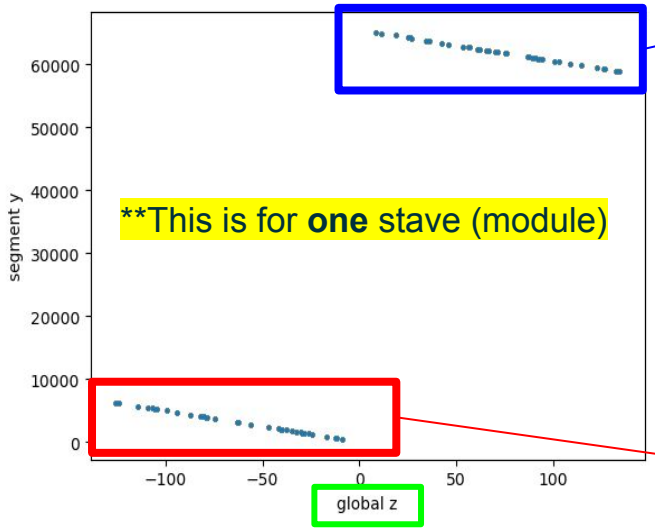


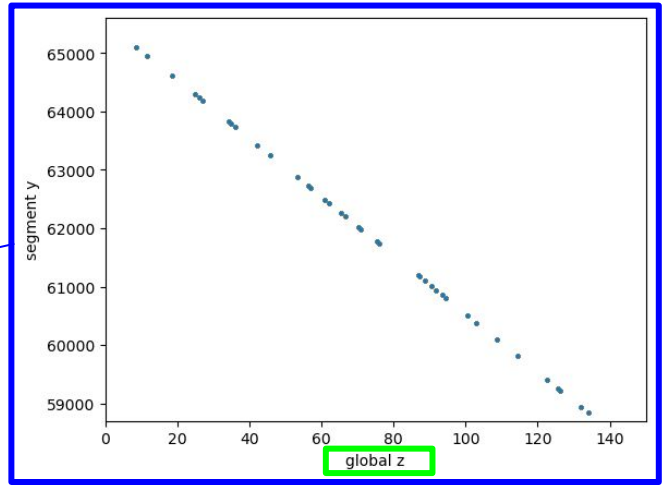
global_phi = np.arctan2(y,x)

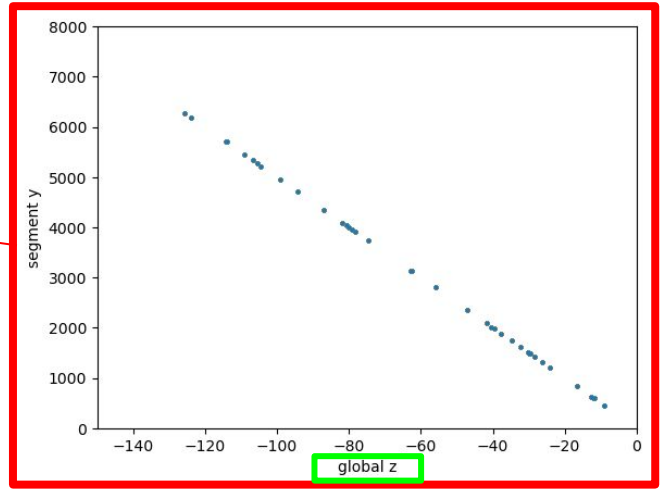
- y=SiBarrelVertxRecHits.position.y
- x= SiBarrelVertxRecHits.position.x

Example Plots for Inner Barrels:

global z vs. segment y

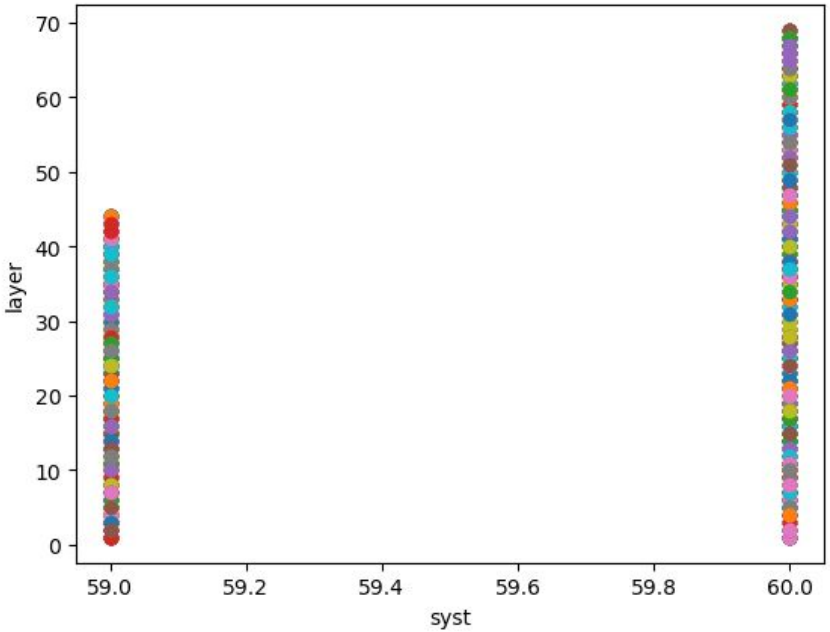




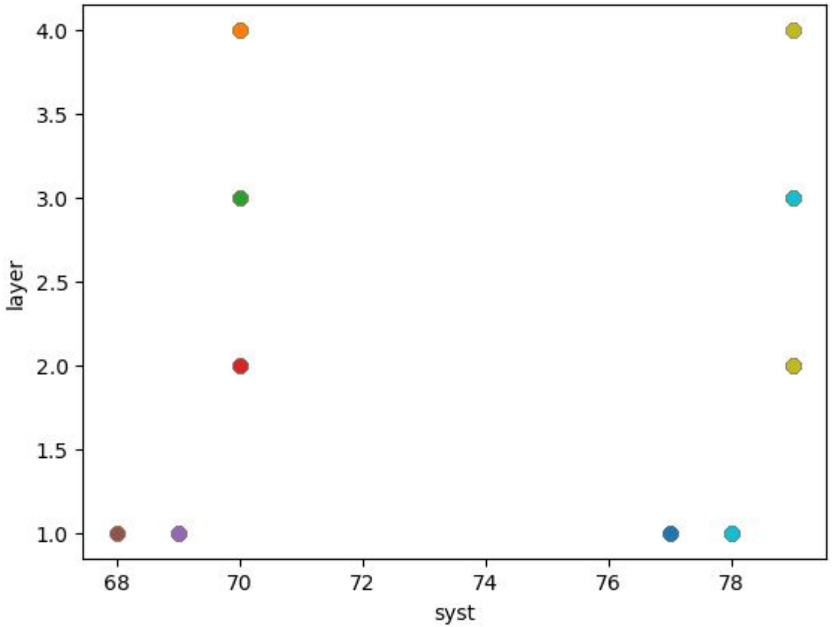


global_z = SiBarrelVertxRecHits.position.z

Example Plots for Outer Barrels and Endcaps (syst vs. layer)



Outer Barrels



End Caps