sPHENIX Report

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Zero-Field Cosmic Display for sPHENIX Tracker including TPC

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1 Run condition and analysis

1.1 MVTX

MVTX operated in the streaming readout mode during the data-taking period and continuously collected data independent of trigger signals.

All chips were configured such that the average of the signal threshold of the pixels on chips was 100 electrons. A global strobe pulse, generated by the MVTX internal trigger, was used as part of a logical AND on each pixel and allowed readout only when it was coincident with a pixel above the threshold. The MVTX detector was configured to be readout in the continuous streaming mode, with an ≈ 89 μs strobe length, which is the duration for the readout unit to be integrated. There are 2 BCOs for MVTX in continuous streaming mode: physics trigger BCO and strobe BCO. Each strobe was assigned a BCO number, MVTX strobe BCO, for internal synchronization. The physics trigger BCO is the same as the strobe BCO when L1 trigger is not fired. When the L1 trigger is fire, the physics trig BCO will be different but synchronize to other subsystems.

In this analysis, we only look at strobes with cosmic trigger fired. It should be pointed out that the L1 cosmic physics trigger BCO for MVTX is the same as TPC and TPOT but +1 away from the INTT. The location of the data is at:

```
/sphenix/lustre01/sphnxpro/commissioning/MVTX/cosmics/cosmics_mvtx-flx
    {0..5}-00025926-0000.evt
```

In this run, MVTX follows similar analysis techniques in the cosmic event display of Run 25475. We converted the MVTX fired pixels after running the private decoder in the 3D world coordinates assuming ideal detector geometry. We also implemented the official sPHENIX clusterizer to clusterize the MVTX hits. The geometric center of the clusters is used to represent the cluster position. The codes can be found on github:

https://github.com/MYOMAO/MVTXINTTEvtDisplay

We group all clusters by the L1 cosmic physics trigger BCO. We apply a selection of at least 2 pixels for all clusters to reject noise. Then, we produce a set of BCOs by requiring at least 3 clusters in each event and pass them to INTT and TPOT groups to hunt for cosmic events.

After the analysis, a list of 238 BCOs is obtained for INTT and TPOT to look for cosmic events.

It is useful to note that a known noisy cluster located at the global position (-4.058740, 0.3005361, -11.97228) was also removed from each display.

1.2 INTT

The INTT operated in the trigger readout mode during the data-taking period. The servers output the hit data to downstream only when receiving the trigger signal. The trigger signal was based on the coincidence of the center of the top and bottom of the Outer HCAL (oHCal). The time-in study with the oHCal trigger was performed prior this run. The *n_collisions* 8 and *modebit* 95 were set. The 270 mV was used to all the chips for the signal threshold. In addition, the nominal calibration-based masking files were loaded for hot-channel-masking purpose. The 40-bit beam crossing counters (BCO) were recorded in data streams and were later used for event synchronization across different INTT FELIX servers.

Location of PRDF is shown below:

```
/bbox/commissioning/INTT/cosmics/cosmics_intt{0..7}-00025926-0000.evt
```

A private decoder was used to convert the raw data into the event-base ROOT trees, server by server. The ROOT files were synchronized based on BCO afterward.

The clustering was performed column by column. The cluster position in xy plane was determined by $\text{pos} = \Sigma_i E_i \cdot \text{pos}_i / \Sigma_i E_i$, where E is the energy deposit quantified by the 3-bit INTT chip, pos is x or y. In the channel-to-position step, the INTT geometry considers the rough systematic offset among the INTT halves. Noting that, the INTT alignment correction is not finalized yet. In the analysis, some known hot spots were masked. The clusters with cluster size greater than 4 were removed. In addition, the events with at least two clusters in the inner layer, and so as the outer layer, was applied to select the cosmic-like events.

1.3 TPOT

TPOT is operated in triggered mode during data taking, at full voltage and with all FEE properly configured. The location of the raw data file is at

```
/bbox/commissioning/TPOT/cosmics/TPOT_ebdc39_cosmics
    -00025926-000{0..2}.evt
```

The procedure for decoding and assembling the raw data events as well as clustering the hits is described here: https://sphenix-invenio.sdcc.bnl.gov/uploads/e3d8s-qrw89

The clusters are stored in

```
/phenix/u/hpereira/sphenix/work/g4simulations/Rootfiles/
    RawDataClusterTree-00025926-0000-full_filtered.root
```

Only events for which there is at least one clusters on both view of one of the 16 TPOT modules are stored.

1.4 TPC

During the data taking period, the sPHENIX TPC operated with a 435 V/cm drift field and 4700 V potential between the top GEM foil and padplane for 58/72 modules (representing 80 % of the TPC's active area). The TPC operated in triggered readout mode, using coincidences between the upper and lower halves of the sPHENIX OHCAL (with a required z flip in the coincidence coordinates). Only 578/624 available FEE cards were read out at the time of the data taking, while 622/624 had link during beginning of Run23. We expect a post-Run23 remote programing of the FEE would bring them back due to single bit upset on the flash programming memory of the FEE.

The PRDF files for the TPC data are located here:

/sphenix/lustre01/sphnxpro/commissioning/tpc/cosmics/TPC_ebdc{00-23}_cosmics-00025926-0000.prdf
/sphenix/lustre01/sphnxpro/commissioning/tpc/cosmics/TPC_ebdc{00-23}_cosmics-00025926-0001.prdf

In offline analysis the following cuts and mappings were made:

- For the 100 frame display shown in Figure 1:
  - The waveforms from the first 100 frames for all sectors from segment 0000 of the run 25926 prdf files were unpacked into TTrees.
  - The figures display approximate (X,Y,Z) positions of hits accumulated over 100 TPC frames. A `frame` value in the unpacked waveform TTree constitutes a single RCDAQ event which is a just a chunk of the TPC data stream. 2 consecutive `frame` values constitute a single event in the detector, allowing for the full $\sim 13\mu$s drfit time.
- For the single BCO cosmic events that display hits from all 4 tracking detectors shown in Figures 4, 3, and 5:
  - All entries in the run 25926 data set were iterated over to find the correct prdf file segment and frame number associated with the BCO value. File segment 0001 contained both BCO values displayed here, and only waveforms with a frame number within $\pm$ 10 frames of the nominal BCO value $\pm$ 50 counts were unpacked into TTrees in order to prevent having to unpack the entire segment 0001 prdf file.
  - The figures display approximate (X,Y,Z) positions of hits accumulated over a single event in the TPC. A `frame` value in the unpacked waveform TTree constitutes a single RCDAQ event which is a just a chunk of the TPC data stream. 2 consecutive `frame` values constitute a single event in the detector, allowing for the full $\sim 13\mu$s drfit time. Thus, for each individual sector, the frame value associated with the listed BCO was found and all hits within that frame and the subsequent frame were included in the display.
  - Individual sectors had different initial frame values associated with the same nominal BCO value, which is why each frame needed to individually have its respective frame value associated with the proper BCO before finding the hits within that sector.
- A hit in this instance is considered any waveform sample with an ADC value at least 5 standard deviations and at least 10 ADC counts above the pedestal mean of the channel. Pedestal mean values and standard deviations were determined using the first 10 data points from all waveforms from a given channel from the complete dataset that was unpacked for that particular display. Additionally, only channels with a pedestal mean greater than 20 ADC, pedestal mean less than 200 ADC, and no checksum error were allowed to be considered hits in order to prevent broken channels from contributing to the display.
- To reconstruct the precise (X,Y) position of each hit using the channel information associated with it, the TPCMap module was used to map channel and sector information to a global position in the TPC. This mapping was recently updated to fix previously incorrect pad plane azimuthal positioning and an initial erroneous FEE mapping.
- To reconstruct an approximate Z position for a hit, the 10th sample in each waveform was assumed to occur at $\pm$ 105 cm, depending on which endcap received the signal, and the

255th sample was assumed to occur at the central membrane (0 cm), with all other hits being evenly spaced between those two limits.

- There was an additional cut on channels with greater than 50 hits that passed the cut conditions mentioned above applied to these images to remove streaky channels in the TPC in order to improve the track visualization quality of the images.
- No clustering, distortion corrections, or tracking software was used in the production of the images.
- The (X,Y,Z) position of each sample and its ADC height above pedestal mean was written out to both a JSON file which can be passed to the sPHENIX Event Display website to view in 3 dimensions, and a root file which can be analyzed at a later time.
- It is useful to note that the innermost 10 cm of the TPC (R = 20-30 cm) is a distortion shaping region and has no signal by design, which is why no hits are seen there.

1.5 TPC 100 time-frame check

This was the first triggered cosmic data, which provided the opportunity to check large scale TPC channel mapping. In particular the cross-sector cosmic rays were used to align the sign of the azimuth channel order for the TPC, as shown in Figure 1.

1.6 Track fit display

We also put the center of the clusters of MVTX + INTT + TPOT together and project them into $x-y$ and $r-z$ plane shown below in Figure 2

In addition, we performed the 3D fit

The fits to MVTX + INTT + TPOT clusters along with TPC clusters demonstrates the functionality of the sPHENIX tracking system. It will help us conduct alignment study and quantify the TPC distortion for calibration purposes.

2 Event display

2.1 Event with sPHENIX BCO Counter of 128330850911

Because of the estimation of the z position in the TPC hits, only MVTX, INTT, and TPOT hits were used to construct the linear track fit shown in these and all other displays. A more precise determination of the drift velocity within the TPC would be required to improve the z position of hits enough to be used in track fitting.

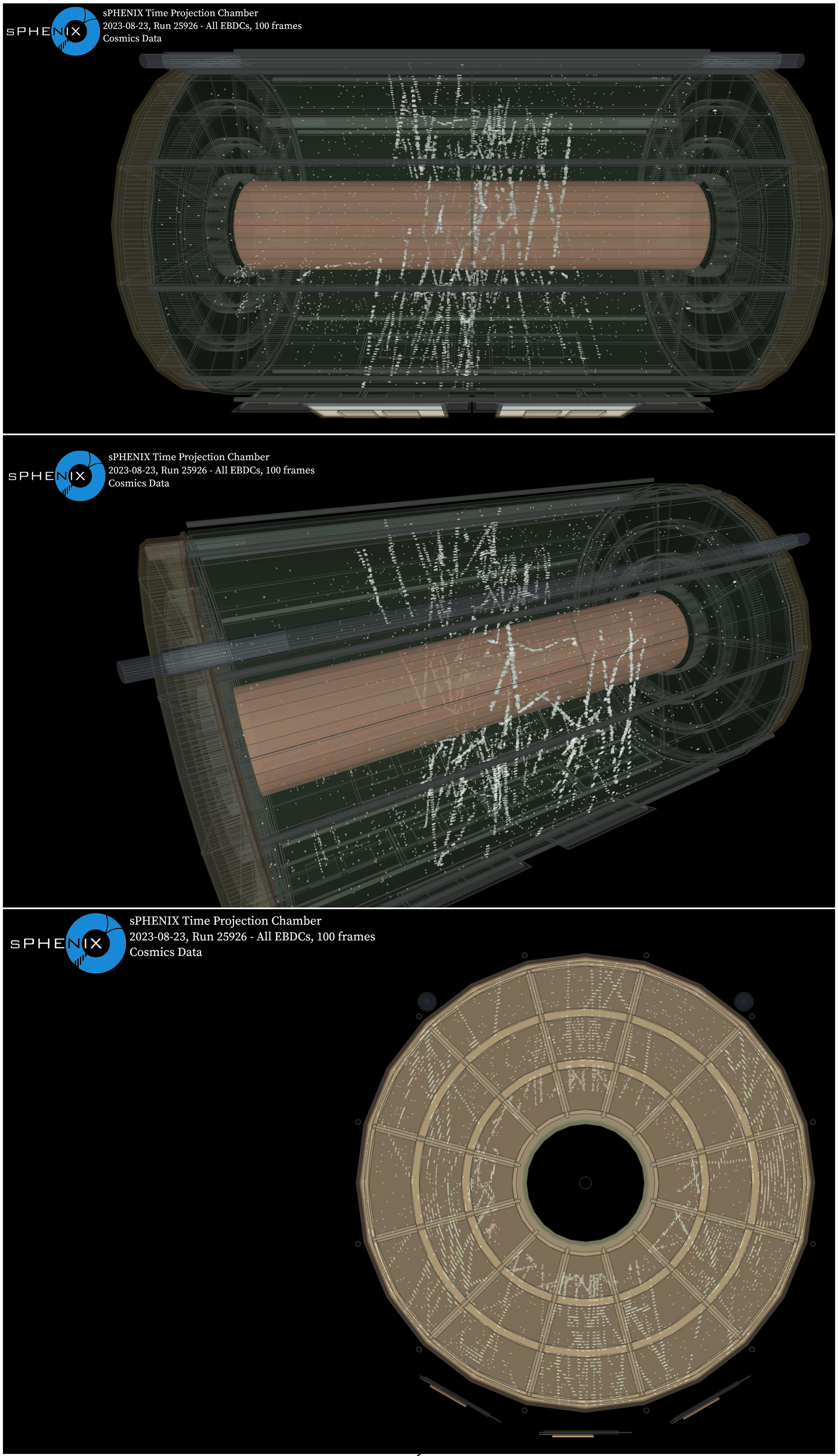

Figure 1: Composition of 100 TPC time frames, each triggered by a HCal cosmic trigger in the center part of the tracking system.

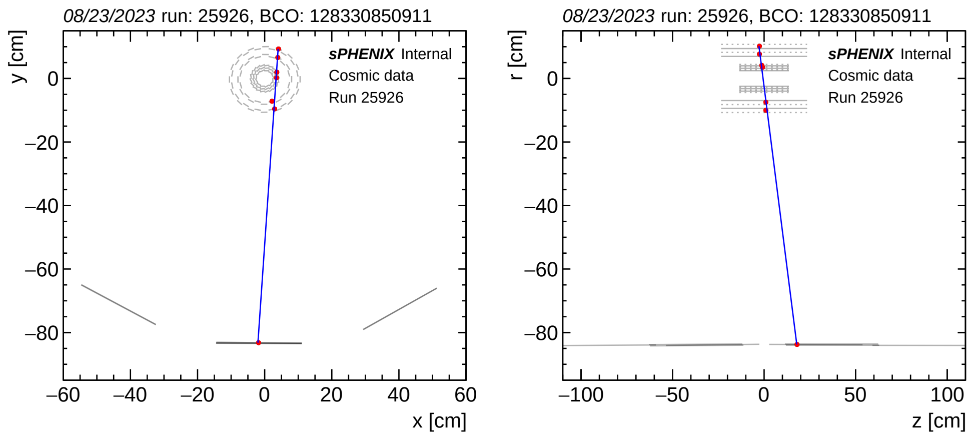

Figure 2: A 2D event display of a straight line fit (blue line) to the the MVTX + INTT + TPOT clusters (red points) in the $x-y$ plane (left) and $r-z$ plane (right) are shown above. The negative sign of r stands for $\phi = \pi$. Good straight fits are observed fopr both plots.

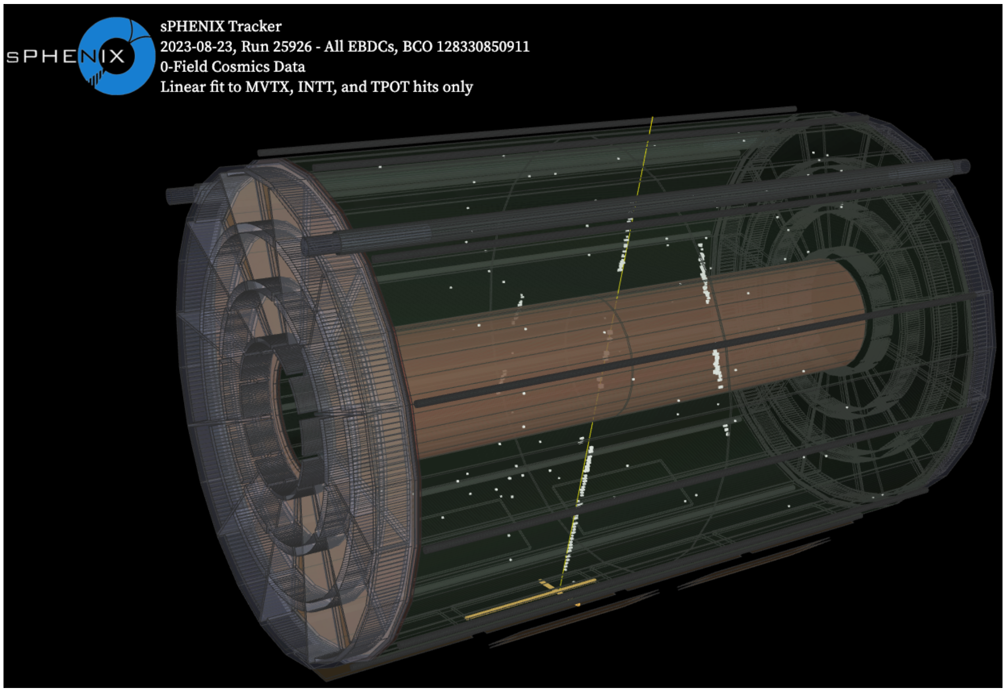

Figure 3: A 3D event display of a straight line fit (yellow line) to the the MVTX + INTT + TPOT clusters (white points) and TPC clusters (white, not in the fit) is shown above. A good straight fit is observed, which demonstrates a cosmic muon track going through and recorded by sPHENIX.

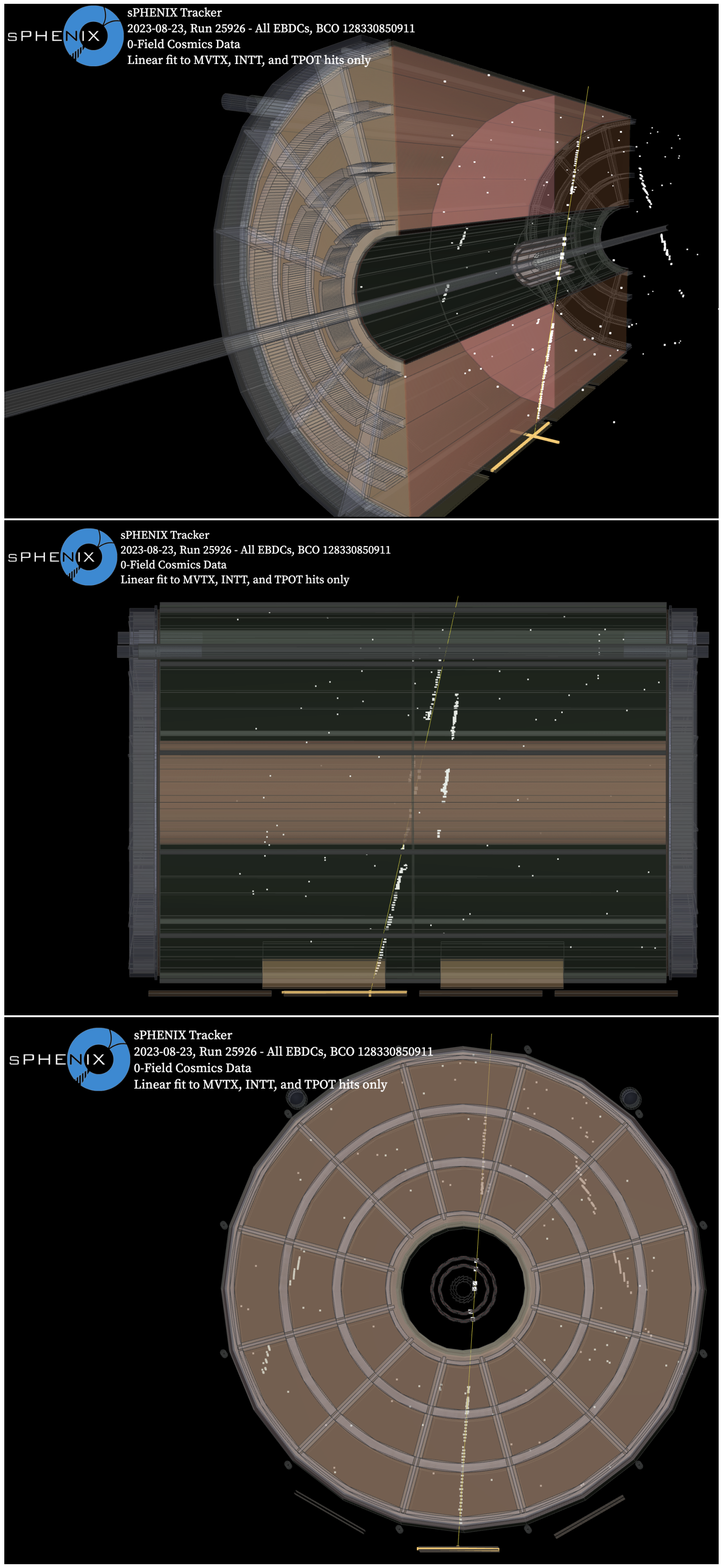

Figure 4: Cosmic Event with sPHENIX BCO Counter of 128330850911. The missing segment of the track at the top of the TPC is GEM module u312, which has a known issue due to suspected GEM deformation and kept at a no-gain voltage setting. Track fit only done using MVTX, INTT, and TPOT hits.

2.2 Event with sPHENIX BCO Counter of 128434038131. This track passed multiple GEM modules that was kept at below operational voltage due to various GEM issues.

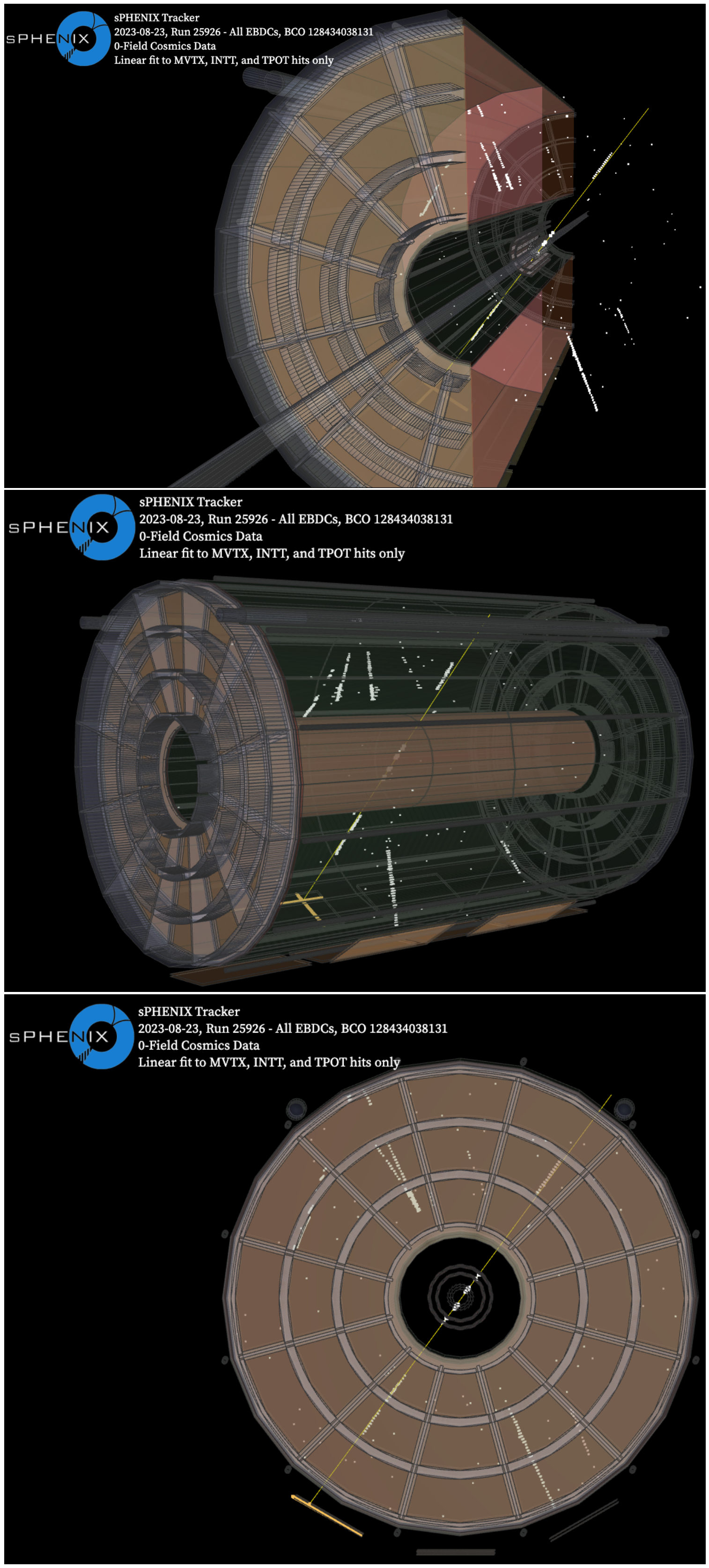

Figure 5: Cosmic Event with sPHENIX BCO Counter of 128434038131. Missing pieces of the track in the TPC unfortunately passed through GEM modules that were kept below operational voltage for various reasons.