

Intermediate Silicon Tracker in sPHENIX at RHIC

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Abstract. The sPHENIX collaboration has been taking data since 2023 at the Relativistic Heavy Ion Collider in BNL to study the Quark-Gluon Plasma and cold Quantum Chromodynamics (QCD). The tracking system of sPHENIX consists of a time projection chamber, a MAPS-based vertex detector, and an intermediate silicon tracker (INTT). Together with the sPHENIX full barrel calorimeter system, the measurement of the heavy-flavor jets and the upsilon-state identification is enabled. INTT, located in the intermediate region of the tracking system and consisting of two layers of silicon strip sensors that surround the beam direction azimuthally, detects hit points to enhance tracking precision. Thanks to the good timing resolution of INTT, it also provides timing information to the corresponding hits of other tracking detectors. This capability eliminates pile-up events due to misidentifying bunch crossings. This proceeding discusses the achievements of INTT using Au+Au collision data taken in 2023, and the status of INTT commissioning with proton+proton collisions in 2024.

1 Introduction

sPHENIX, a new collider experiment built after 20-year operation of the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory, is a state-of-the-art jet detector aiming to study the strongly interacting Quark-Gluon Plasma and cold Quantum Chromodynamics by measuring jets, jet correlations, and leptons with high precision [1]. Figure 1 shows the cutaway rendering of the sPHENIX detector. Driven by these goals, the sPHENIX detector features large acceptance, full barrel calorimeters, a 1.4 Tesla solenoid magnet, and an advanced tracking system. The full barrel calorimeter system, first time available at RHIC, stands for the electromagnetic calorimeter (EMCal), and inner and outer hadronic calorimeters (iHCal and oHCal). The tracking system of sPHENIX is composed of a monolithic active pixel sensor vertex detector (MVTX) for the vertex measurement, an intermediate silicon tracker (INTT) for the track timing information, a time projection chamber (TPC) for the track momentum measurement, and a TPC outer tracker (TPOT) for the TPC-distortion calibration. Together, these components cover a full azimuthal angle and pseudorapidity $|\eta| < 1.1$ for collision vertices located within ± 10 cm of the nominal interaction point along the beam axis.

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INTT is a two-layer barrel strip tracker located in the intermediate region of the sPHENIX tracking system. The INTT ladders [2], which are the detection units of the INTT, are staggered in a cylindrical configuration around the beam pipe at radial positions of approximately 7.5 cm (inner barrel) and 10 cm (outer barrel) from the beam axis. INTT offers two spatial points to bridge tracks of the MVTX and TPC, and enhance the pattern recognition [3]. In addition, the timing resolution of INTT, which is finer than the bunch-crossing frequency of RHIC and is the best in the tracking system, enables INTT to associate reconstructed tracks with individual RHIC bunch crossings, eliminating pile-up events. The mechanical drawing of INTT is shown in Figure 1. The INTT strips are 78 μm in pitch width, 20 or 16 mm in length, which give INTT a good spatial resolution in polar angle, while the resolution in determining the hit position in the beam direction (the z -axis) is relatively coarse.

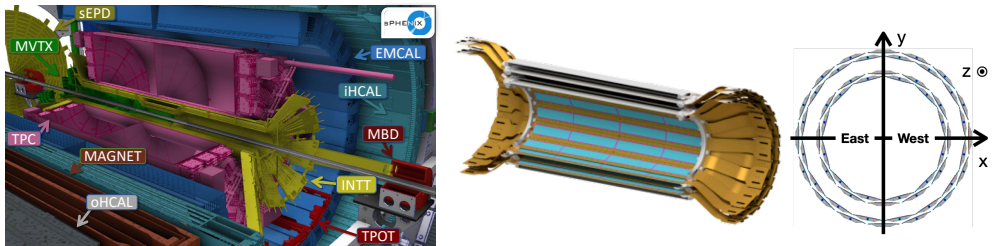


Figure 1. Left: Rendering of the sPHENIX detector. Middle and Right: Schematic and cross-section view of INTT, respectively.

2 INTT performance in Au+Au collisions in year 2023

After more than 10 years of preparation, sPHENIX started to take data with Au+Au collisions in May 2023 [4]. INTT was commissioned in the triggered-readout mode shortly after. Figure 2 shows the correlation between the measured multiplicity of the Minimum Bias Detector (MBD) of sPHENIX and that of INTT. The positive correlation is identified, indicating that the INTT and MBD are timed in, and the recorded data in both subsystems are reliable.

Additionally, comprehensive analyses were conducted to enhance the understanding of INTT, such as the z -vertex (z_{vtx}) reconstruction. A strip tracker is not conventionally designed for reconstructing the collision vertex, as its strip lengths, on the order of centimeters, may be coarse for this purpose. The potential of which by INTT was investigated since it could potentially provide a valuable reference for calibrating the z -vertex measured by MBD. The procedures of the reconstruction algorithm developed for INTT are briefly described as follows. Inner-barrel clusters are paired with outer-barrel clusters. Pairs with small differences in azimuthal angle are retained as tracklets. Since a particle can interact with an INTT strip at any position along its length in the beam direction (the z -axis), the probability distribution of collision location inferred from a tracklet is in the shape of a trapezoid, as demonstrated in Figure 3. By stacking the trapezoidal shapes formed by all the tracklets in a single event, a Gaussian-like distribution is formed. The example is shown in Figure 3. The z_{vtx} of an event is determined by the average fit Gaussian means. The performance of this approach with INTT was evaluated in simulation, as shown in Figure 4. The resolution can reach up to 1.7 mm in events with the number of clusters exceeding one thousand, which is 10 times smaller than the intrinsic strip length of INTT. The algorithm was also applied to data, and the z -vertices measured by MBD and INTT were compared, as shown in Figure 4.

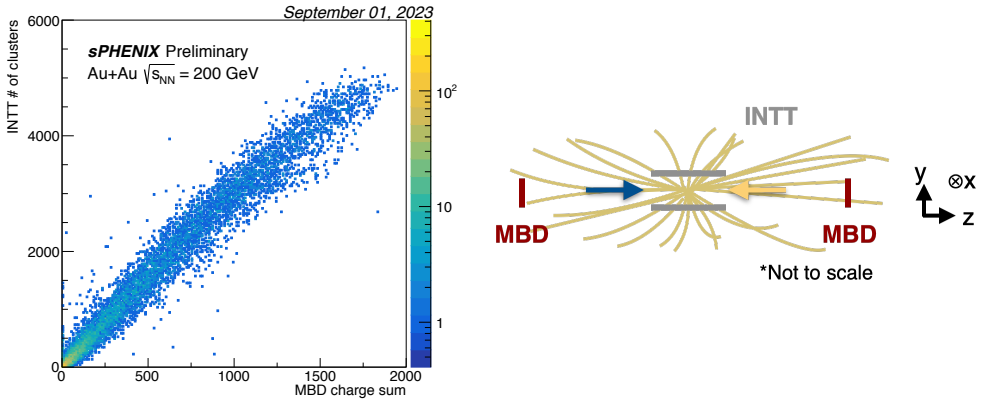


Figure 2. Left: Correlation between the MBD total charge and the INTT number of clusters. Right: Illustrating the relative locations of INTT and MBD.

The positive correlation with the slope close to unity validates the algorithm and provides additional confirmation of the integrity of the INTT recorded data.

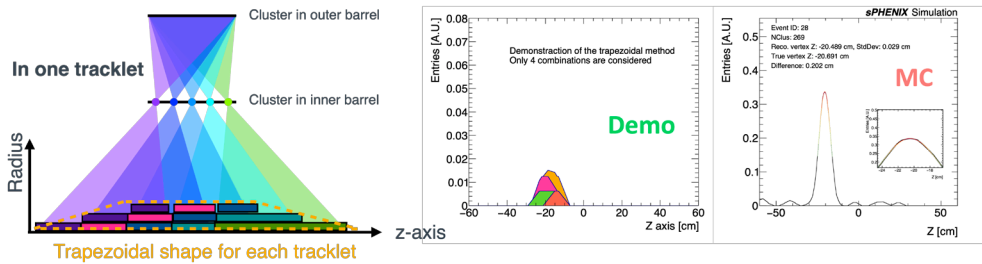


Figure 3. Left: Demonstration of the probability distribution of collision location in the z-axis inferred from one tracklet. Middle and Right: The Gaussian-like distribution formed by stacking up the trapezoidal shapes of the tracklets in demonstration and simulation, respectively.

3 INTT performance in proton+proton collisions in year 2024

In 2024, sPHENIX started to collect the proton+proton collision data in April. During the data taking, the INTT data acquisition mode was transitioned to a streaming readout mode. Unlike the triggered-readout mode, which keeps events only if triggers are fired, such as the EMCAL photon trigger, the streaming readout mode enables recording events as long as the particle hits are detected by INTT. The streaming readout is crucial for the sPHENIX heavy-flavor physics program as the objects of interest are not energetic enough to fire the triggers [5]. Figure 5 shows the number of INTT hit counts as a function of bunch crossing (BCO) index. The bin in red indicates the collected hits associated with a trigger, while the spikes in black represent the recorded hits from the rest of the collision events without a trigger fired. The capability of INTT operating in streaming readout mode is demonstrated. Besides, the cluster multiplicities of two INTT barrels were correlated as a sanity check, as

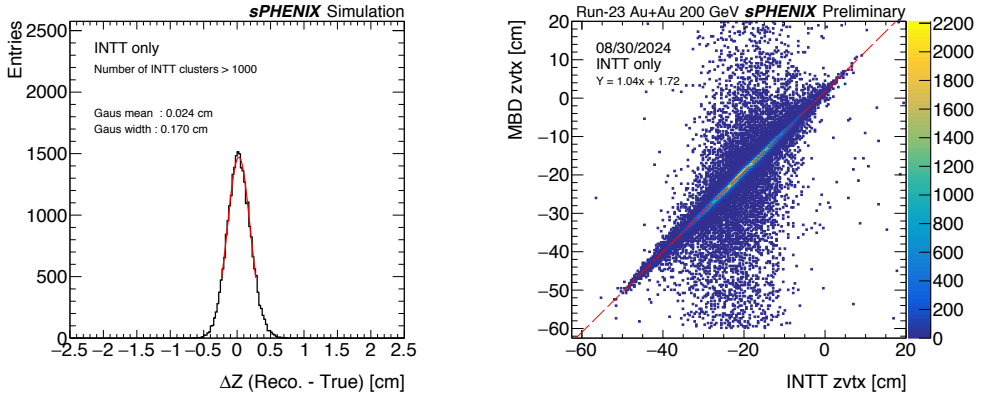


Figure 4. Left: Distribution of difference between the reconstructed INTT z_{vtx} and truth z_{vtx} in simulation. Right: Correlation between the z-vertices reconstructed by INTT and MBD in data.

shown in Figure 5. The observed positive correlation suggests that the INTT operation in streaming readout mode is functioning as expected.

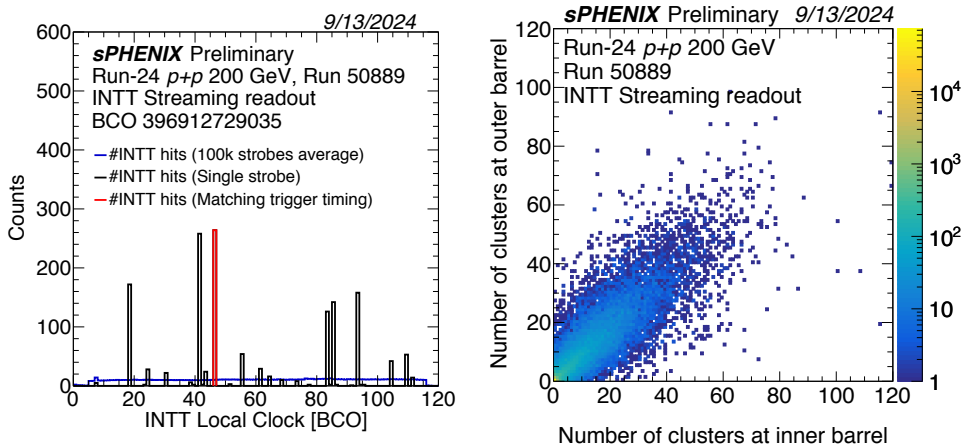


Figure 5. Left: INTT hit counts as a function of bunch crossing index in a single time frame. Right: Correlation between the INTT numbers of inner-barrel clusters and outer-barrel clusters.

The detailed analyses were further performed with the aim of gaining more insights into the recorded streaming data, such as the INTT standalone track reconstruction. An event display is shown in Figure 6. Particle tracks are reconstructed by utilizing the INTT clusters on top of the vertex reconstruction. The bending curvatures of charged particles due to the magnetic field are clearly identified. The mission as a tracker is proven to be achievable. Furthermore, an evident incident-angle dependence was observed in the study of particle energy deposition in the INTT sensors, as shown in Figure 7. A smaller particle incident angle leads to a longer traverse length, resulting in a larger amount of energy deposited in the

INTT sensor. The measured result, exhibiting a consistent trend, confirms that the recorded data predominantly consists of signal hits.

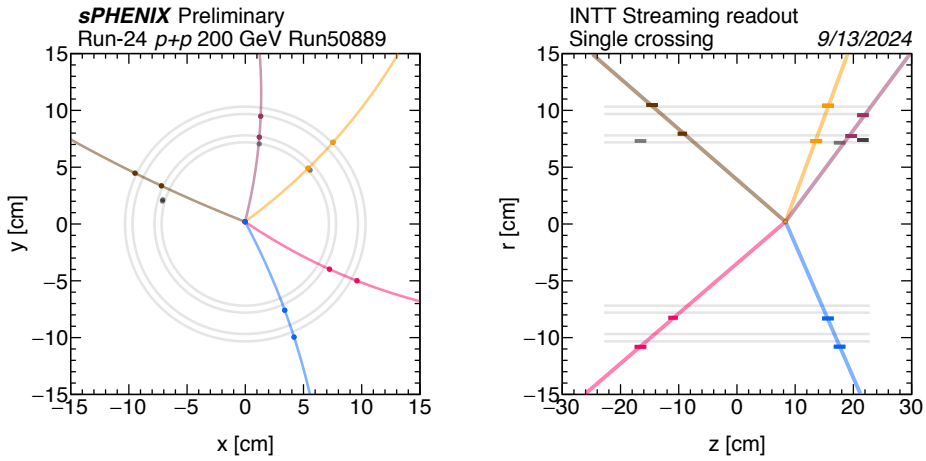


Figure 6. Event display of INTT performing track reconstruction with INTT clusters in the x-y plane (Left) and the z-radius plane (Right).

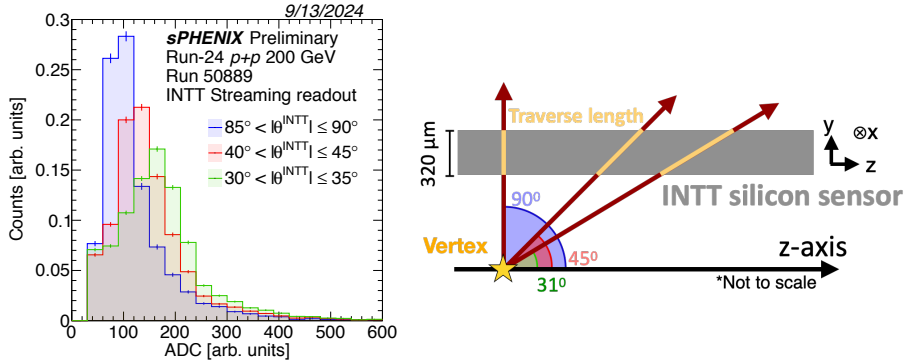


Figure 7. Left: INTT energy deposit distributions with different particle incident-angle intervals. Right: Illustrating the relation between particle incident angle and traverse length in the INTT sensor.

4 Conclusion

The timing resolution of INTT, which is finer than the bunch-crossing frequency of RHIC, makes it the only tracking detector in sPHENIX capable of associating individual tracks with events. In Run 2023, sPHENIX started commissioning with Au+Au collisions, during which a correlation in multiplicity between INTT and MBD was identified. Besides, the z-vertices reconstructed by INTT and MBD showed a positive correlation with a slope close to unity. During Run 2024, when sPHENIX collected proton+proton collision data, INTT transitioned

to the streaming readout mode. This is crucial for the sPHENIX heavy-flavor physics program, as all collision events can be recorded. In the streaming readout mode, a clear multiplicity correlation was observed between the INTT inner and outer barrels. In addition, the developed INTT tracklet analysis was able to reconstruct particle tracks. Moreover, the distinct particle incident-angle dependence of energy deposition in the INTT sensor was concluded. INTT has been confirmed to be in good condition and reliable in both Run 2023 and Run 2024! With the substantial statistics taken, sPHENIX is going to deliver exciting physics results!

References

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