Implemention of ACTS into sPHENIX Track Reconstruction

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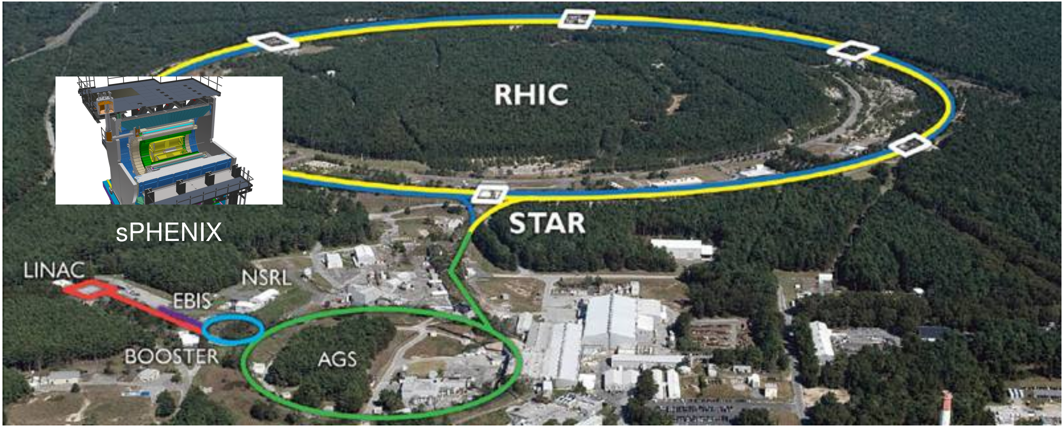
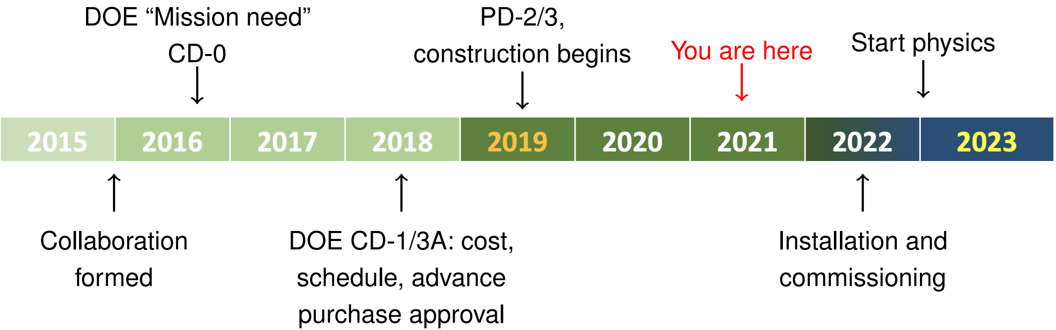
Next Generation of QCD at RHIC



The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory

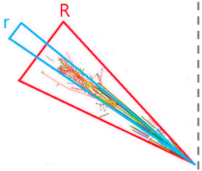
Collaboration Timeline



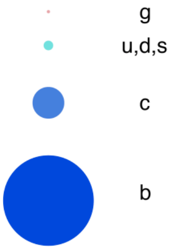
sPHENIX

Jet correlation & substructure

Vary momentum/ angular size of probe

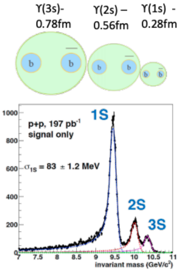


Parton energy loss Vary mass/ momentum of probe



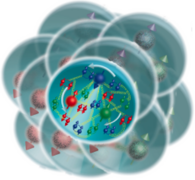
Upsilon spectroscopy

Vary size of the probe



Cold QCD

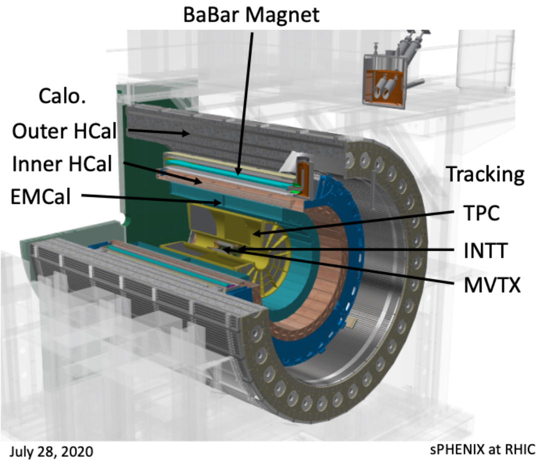
Vary temperature of QCD matter



- Study QCD matter at varying temperatures for direct comparisons to LHC
- Study partonic structure of protons and nuclei

sPHENIX Detector

- sPHENIX detector designed for high precision tracking and jet measurements at RHIC
  - Large, hermetic acceptance
  - Hadronic calorimetery (first at RHIC)
  - Huge data rate for collecting large minimum bias sample



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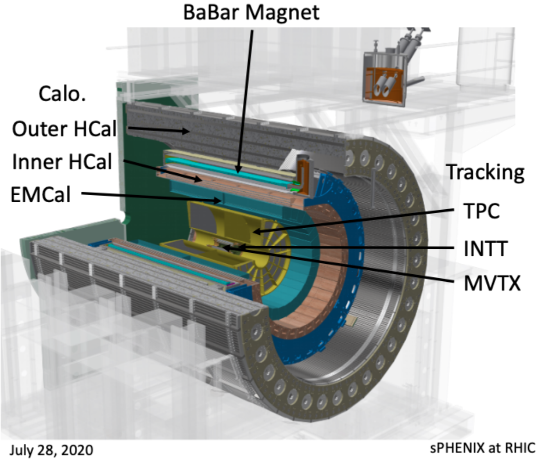
- Primary tracking detectors:
  - Micro vertexing (MVTX) - 3 layers of MAPS staves
  - Intermediate silicon tracker (INTT) - 2 layers of silicon strips
  - Compact GEM-based TPC - continuous readout



sPHENIX Computing Challenges

- RHIC will deliver Au+Au collisions at 50 kHz, while sPHENIX will record at 15 kHz
- In a 3 year, $\sim$24 cryo-week per year data taking campaign, sPHENIX will collect $\sim$ 250 PB of data
- Data will be processed on a fixed size computational farm at BNL
- Necessitates fast, efficient track reconstruction to achieve physics goals
    - Goal is a CPU budget of 5 seconds-per-event on a single tracking pass

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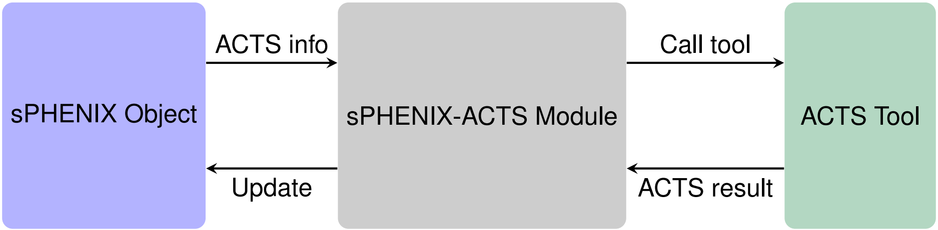
- Additionally, TPC will contain charge from 2-3 Au+Au collisions at a given time
  - Hit occupancies of $\mathcal{O}$(100,000) expected
- Track reconstruction must be robust to high occupancies from pile up charge

sPHENIX-ACTS Track Reconstruction

- To work towards meeting these goals, sPHENIX has implemented the A Common Tracking Software (ACTS) toolkit into our software stack
- ACTS is intended to be a modern, performant, flexible track reconstruction toolkit that is experiment independent
- Largely developed by ATLAS tracking experts; however, user/developer base has grown
- ACTS has modern development practices, e.g.
  - Semantic versioning/releases
  - Full CI/CD implemented in Github Actions
  - Issue tracking
  - Documentation
  - Unit testing
  - . . .

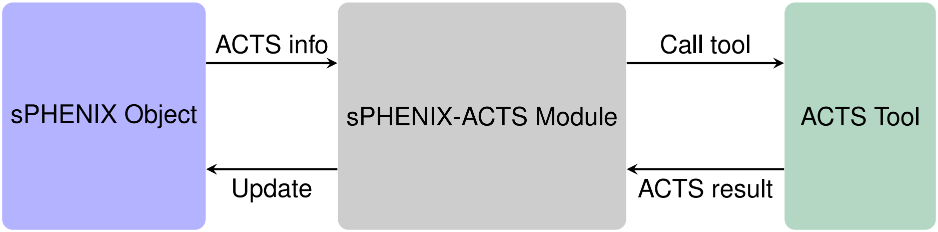
ACTS Github link

ACTS Implementation Strategy



- ACTS requires geometry and measurement objects (that's all)
- sPHENIX objects store necessary information for ACTS objects
- Modules act as wrappers for calling ACTS tools and updating sPHENIX objects

ACTS Implementation Strategy



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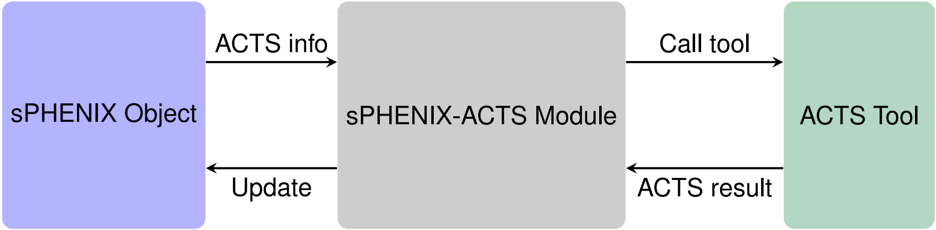

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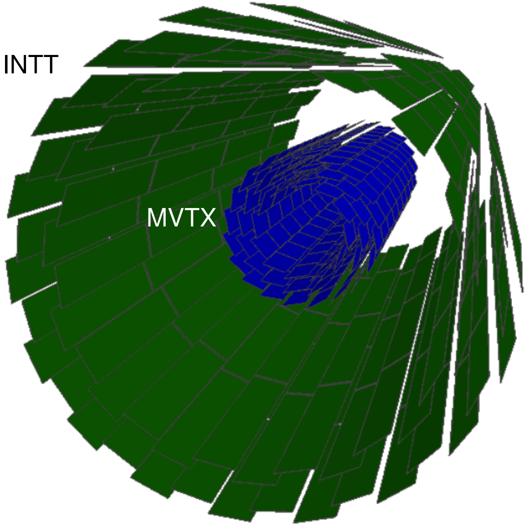
- Fun4All-sPHENIX code available on Github - feel free to ask for more details

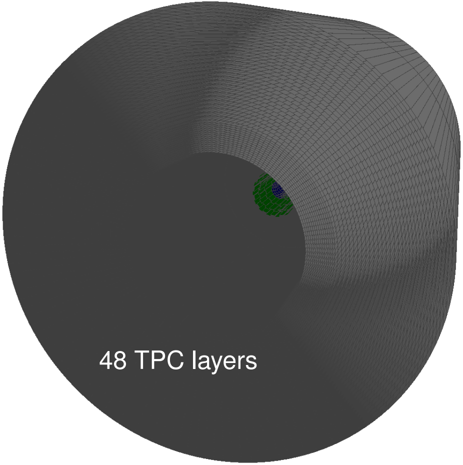
ACTS Geometry - Silicon

- ACTS is able to perform material calculations quickly due to a simplified geometry model
- ACTS contains an available `TGeometry` plugin which takes `TGeoNodes` and builds `Acts::Surfaces`
- Any changes to sPHENIX GEANT 4 silicon surfaces are ported to ACTS geometry in the background

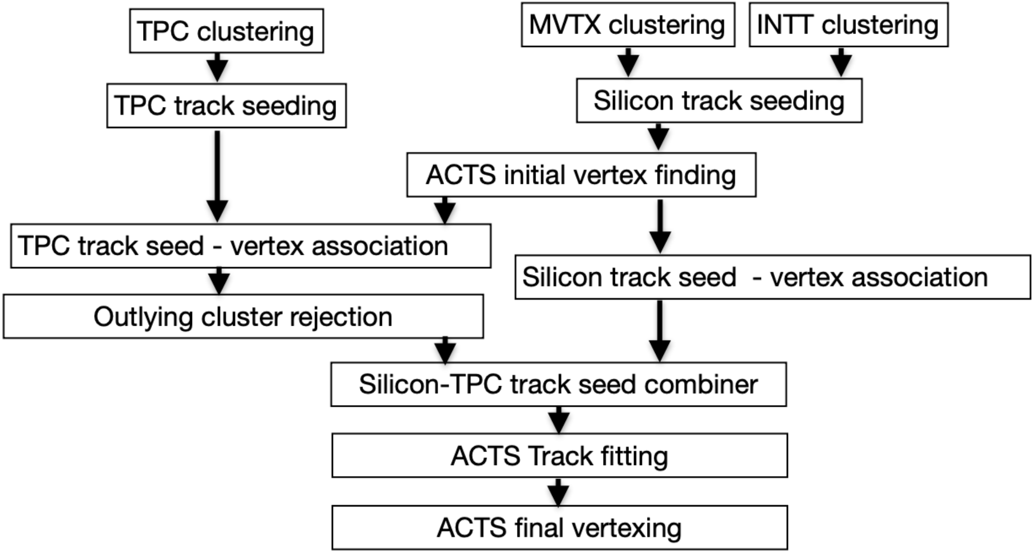


ACTS Geometry - TPC

- ACTS geometry model not immediately suited to TPC geometries, since surfaces are required
- With TPC, charge can exist anywhere in 3D volume
  - Side note: ongoing development within ACTS to allow for 3D fitting
- In place, create planar surfaces that mock cylindrical surfaces
- Surfaces are set at readout layers, so there is a direct mapping from a TPC readout module to *n* planar surfaces



Track Reconstruction Strategy



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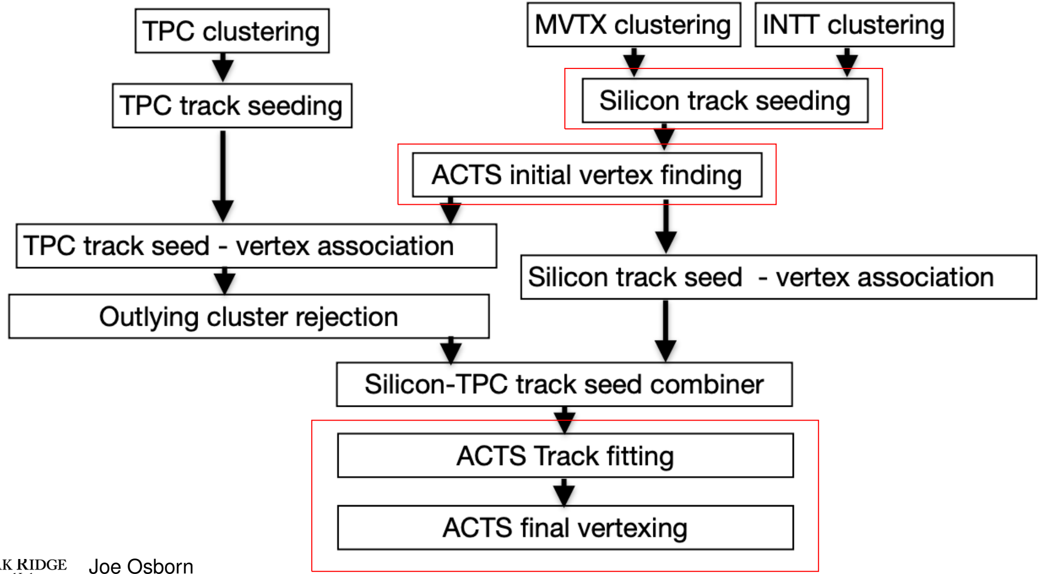
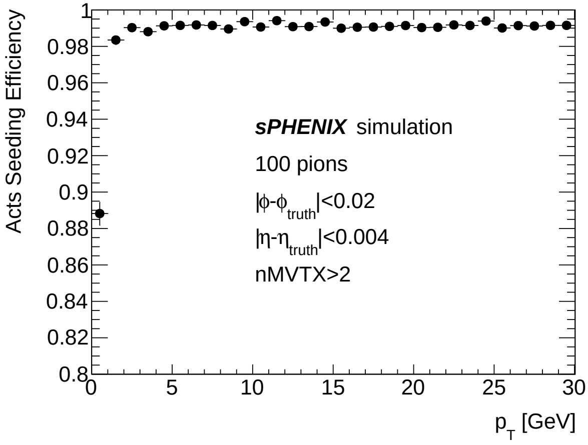


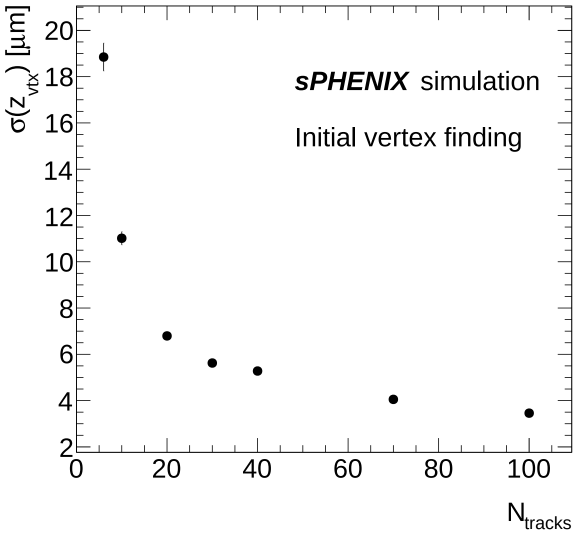
Silicon Seeding



- ACTS track seeding tool takes a list of space points and creates three-measurement seeds
  - Ideally suited for MVTX, which has 3 layers
- ACTS seeding efficiency shown in 100 pion events
- MVTX triplets are propagated to INTT to find additional measurements
- Final output is a set of 3-5 measurement silicon seeds

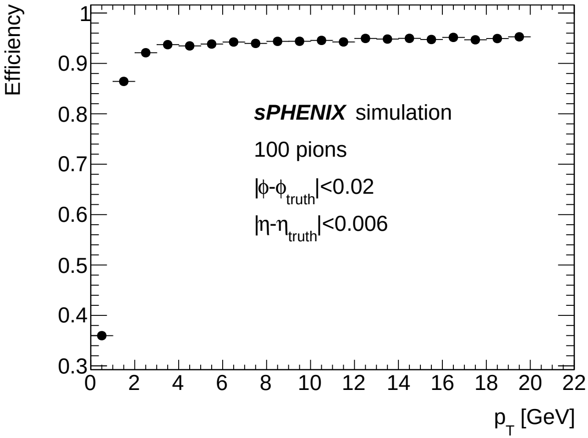
ACTS Vertex Finding

- Silicon track seeds have excellent spatial resolution, and almost entirely define the event vertex
- `Acts::IterativeVertexFinder` is used to assign silicon seeds a vertex position
- Seeds are clustered to identify outliers and remaining seeds are provided to the ACTS tool



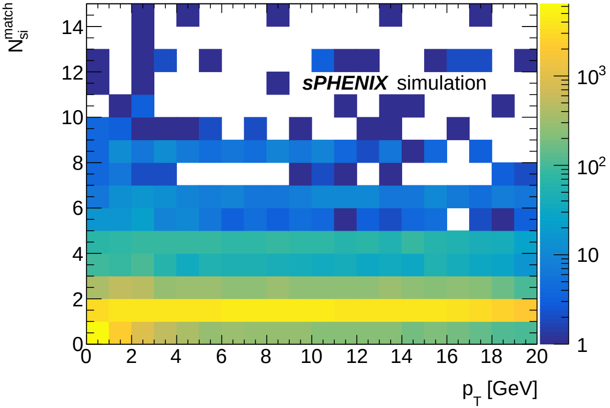
CA Seeding in TPC

- Independently (from ACTS) developed Cellular Automaton seeder is deployed in TPC
- Measurement gathering algorithm is a reimplementation of concept underpinning ALICE TPC tracking software
- Seeder is efficient - continuing development on producing high quality seeds encompassing entire TPC



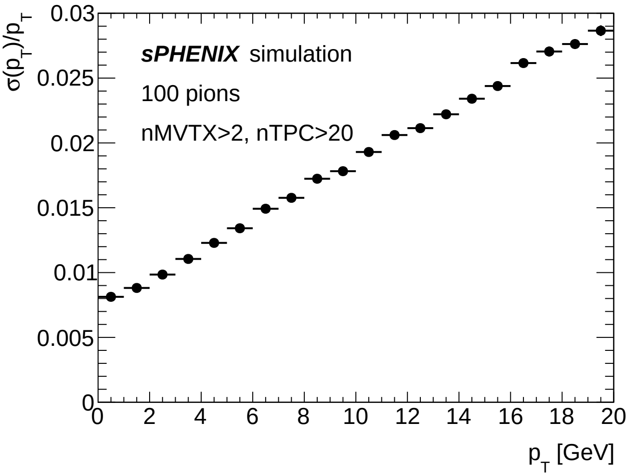
Track Matching

- Track seeds in silicon and TPC are matched to one another with ϕ/η windows
- Windows tuned to limit duplicate matches while ensuring real tracks are matched
- ACTS fitter (next page) is very good at identifying bad seeds in sPHENIX geometry



Track Fitting

- Use `Acts::KalmanFitter` tool to fit full assembled track seeds
- Tool performs a full fit outwards, then smooths result inwards to vertex
- ACTS::KF performs well, meeting sPHENIX physics goals



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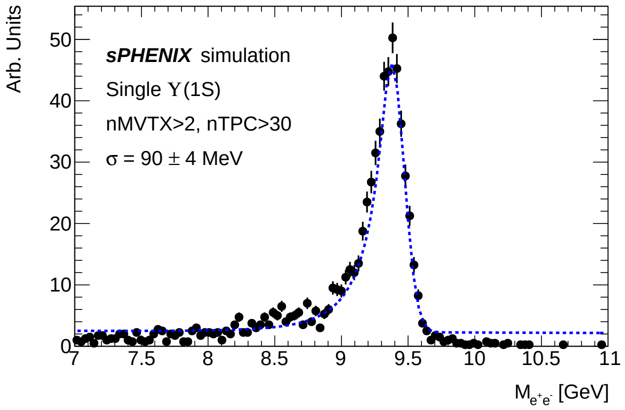
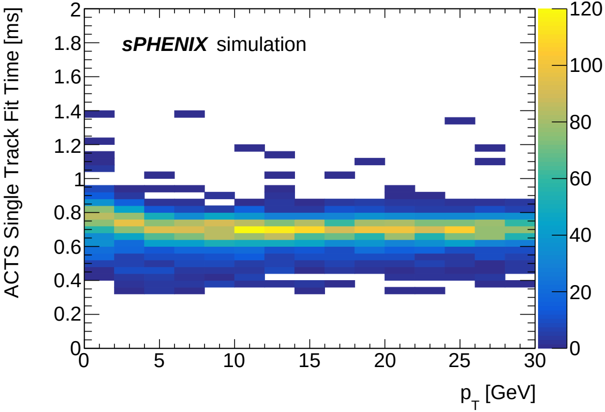
- Single upsilon mass spectrum meets sPHENIX physics goals

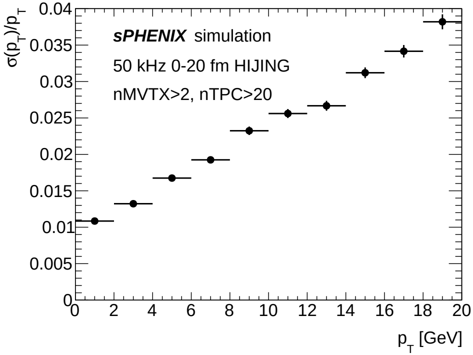


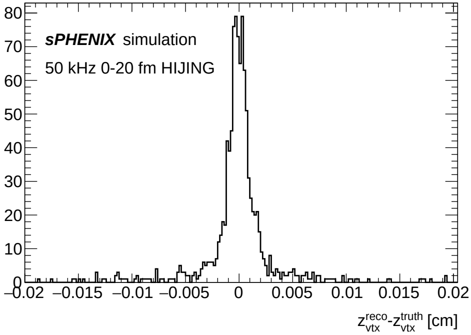
Track Fit Timing



- One of the primary motivations for switching to ACTS was for speed
- `Acts::KalmanFitter` time-per-track is shown here with sPHENIX silicon+TPC geometry
- After ACTS +CA seeding implementation, sPHENIX track reconstruction is $\mathcal{O}(10)$x faster than previous implementations

High Occupancy Performance



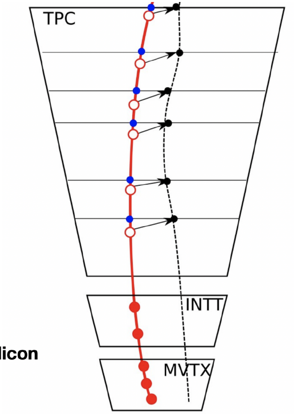


- High occupancy performance continues to be tuned and improved
- So far sPHENIX p_T, DCA resolution goals can be met with current implementation
- Continued work on :
    - Improving quality of track seeds
    - Reducing number of ghost/duplicate track seeds

TPC Space Charge Distortions

48 layers of TPC

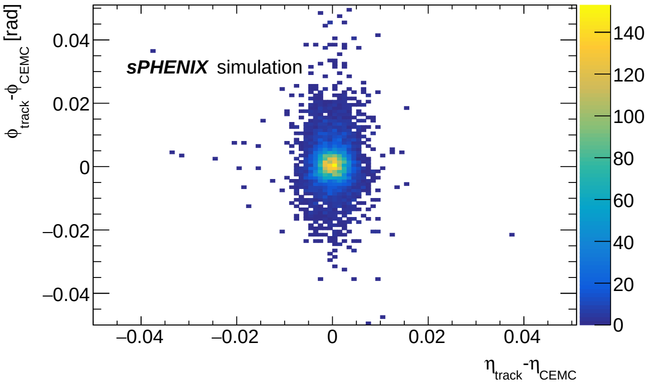
5 layers of silicon



- Space charge buildup from ion back flow in the TPC distorts measurements from true position
- Presents a challenge within ACTS due to 2D surface description
- Ongoing development:
  - Within sPHENIX - shift measurements along surfaces that account for full 3D distortions
  - Within ACTS - Full 3D track fitting to accomodate TPC/DC geometries

ACTS Tools

- ACTS tools described so far are "pre-packaged"
- Versatility of ACTS - `Acts::Propagator`, used in `Acts::KalmanFitter`, can be used freely as a tool
- Use propagator to identify track states for TPC space charge distortions and track-to-calorimeter projections
- Tools are available for experiments to explore new and/or unforeseen use cases



Conclusions

- sPHENIX is the next generation QCD experiment being constructed at RHIC
- RHIC will deliver highest luminosities ever to sPHENIX, resulting in large hit occupancies
- To reconstruct data in a timely manner, sPHENIX has recently implemented the ACTS toolkit into our software stack
    - First implementation of TPC in ACTS - more development ongoing both within ACTS and sPHENIX
- We have the ACTS seeding, vertexing, and fitting tools deployed in our default track reconstruction. Have explored other ACTS tools as well
- Development is active and ongoing as we prepare for commissioning and data taking in 2022/2023!