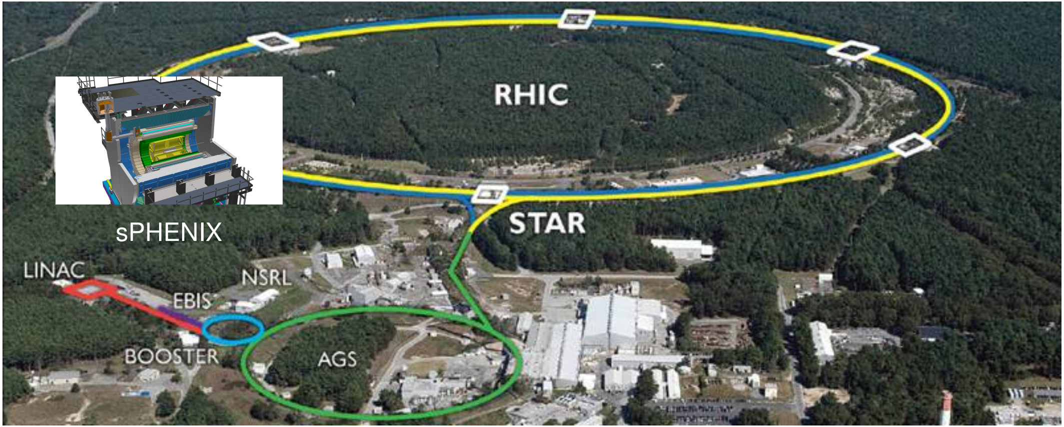
Implemention of ACTS into sPHENIX Track Reconstruction

Joe Osborn

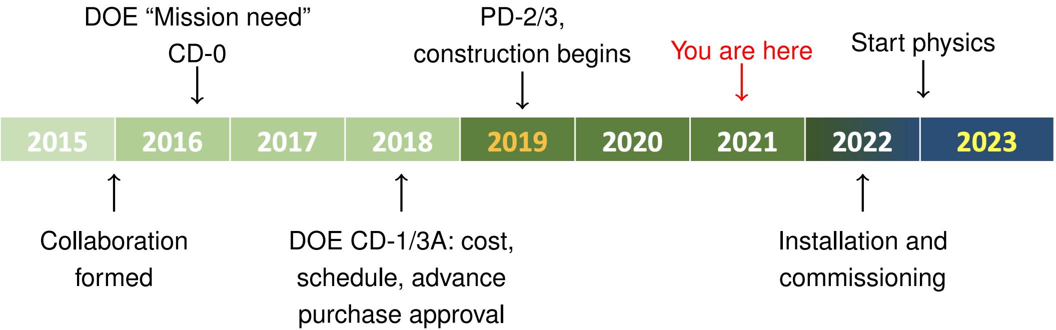
May 17, 2021

Next Generation of QCD at RHIC



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

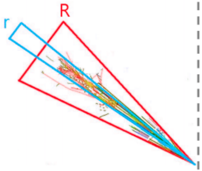
Collaboration Timeline



sPHENIX

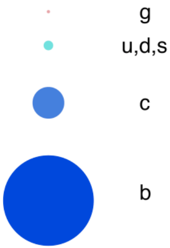
Jet correlation & substructure

Vary momentum/ angular size of probe



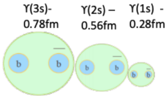
Parton energy loss

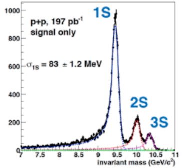
Vary mass/ momentum of probe



Upsilon spectroscopy

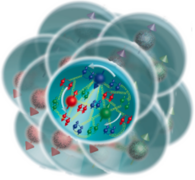
Vary size of the probe





Cold QCD

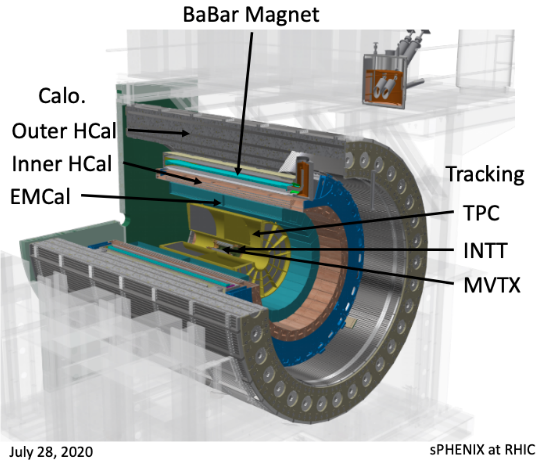
Vary temperature of QCD matter



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

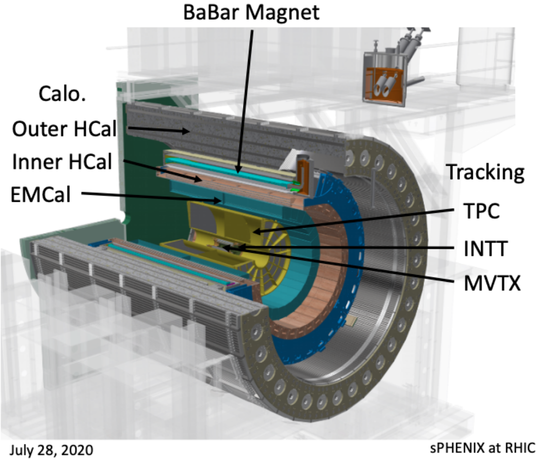
sPHENIX Detector

- sPHENIX detector designed for high precision tracking and jet measurements at RHIC
  - Large, hermetic acceptance
  - Hadronic calorimetery (first at RHIC)
  - Large offline data rate of $\sim$100 Gbit/s for collecting large minimum bias sample



sPHENIX Detector

- sPHENIX detector designed for high precision tracking and jet measurements at RHIC
  - Large, hermetic acceptance
  - Hadronic calorimetery (first at RHIC)
  - Large offline data rate of $\sim$100 Gbit/s for collecting large minimum bias sample
- Primary tracking detectors:
  - Micro vertexing (MVTX) - 3 layers of MAPS staves
  - Intermediate silicon tracker (INTT) - 2 layers of silicon strips (fast integration time)
  - Compact GEM-based TPC - continuous readout



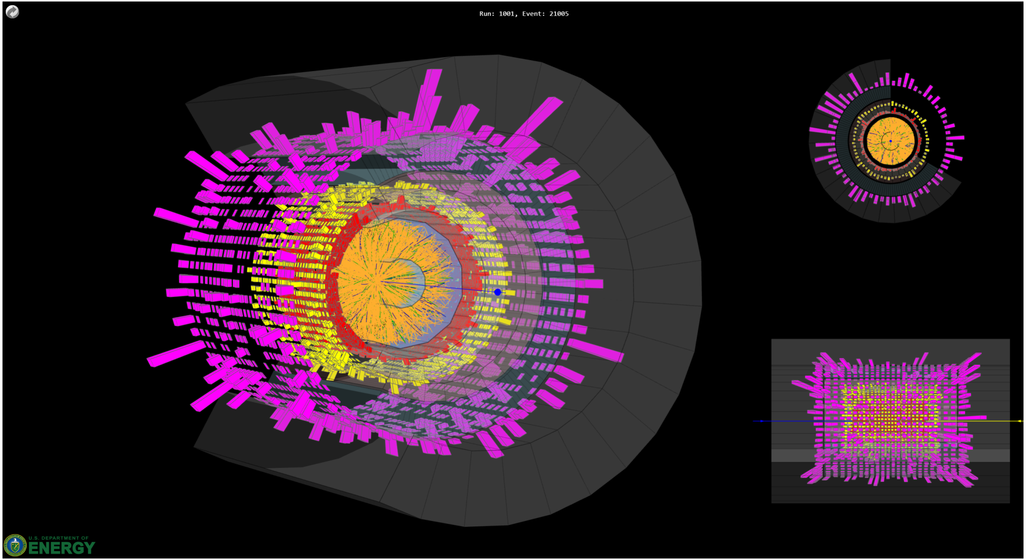
sPHENIX Computing Challenges

- 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
    - Goal is a CPU budget of 5 seconds-per-event on a single tracking pass

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
  - Goal is a CPU budget of 5 seconds-per-event on a single tracking pass
- Additionally, TPC will contain charge from 2-3 Au+Au collisions at a given time
  - Hit occupancies of $\mathcal{O}$(100,000) expected

sPHENIX Computing Challenges



PB

sPHENIX Computing Challenges

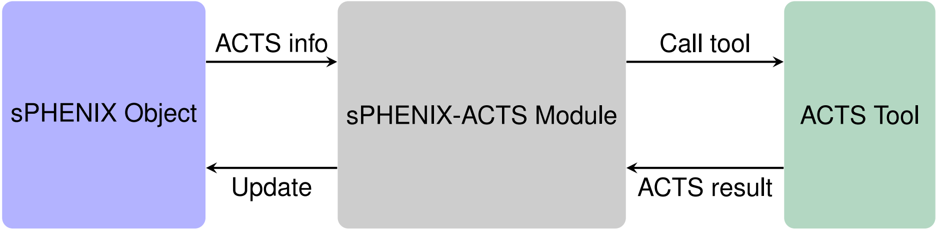
- RHIC will deliver Au+Au collisions at 50 kHz, while sPHENIX will record at 15 kHz
- In a 3 year, $\sim$24 cryo-week per year data taking campaign, sPHENIX will collect $\sim$ 250 PB of data
- Data will be processed on a fixed size computational farm at BNL
- Necessitates fast, efficient track reconstruction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

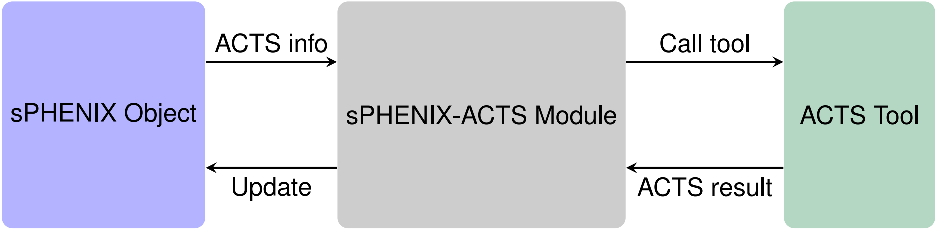
ACTS Github link

ACTS Implementation Strategy



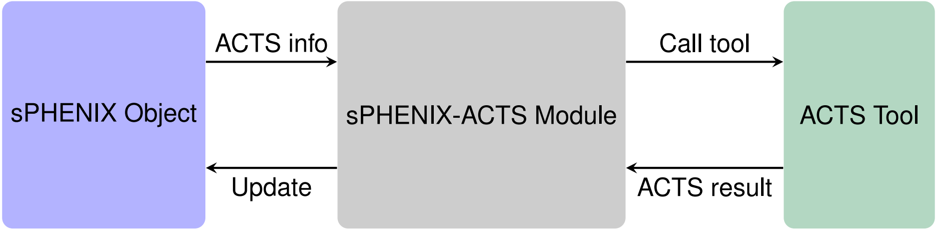
- ACTS requires geometry and measurement objects (that's all)
- sPHENIX objects store necessary information for ACTS objects
- Modules act as wrappers for calling ACTS tools and updating sPHENIX objects

ACTS Implementation Strategy



- 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
- Eventually plan to move to a paradigm where sPHENIX objects == ACTS objects, for saving memory and time

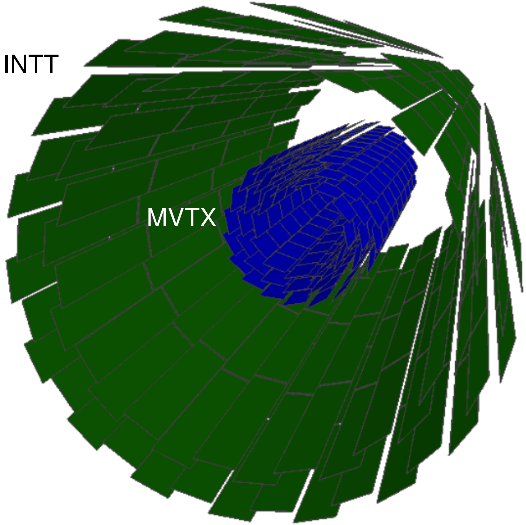
ACTS Implementation Strategy



- 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
- Eventually plan to move to a paradigm where sPHENIX objects == ACTS objects, for saving memory and time
- Fun4All-sPHENIX code available on Github - code is open source and containerized with Singularity. Feel free to ask for more details!

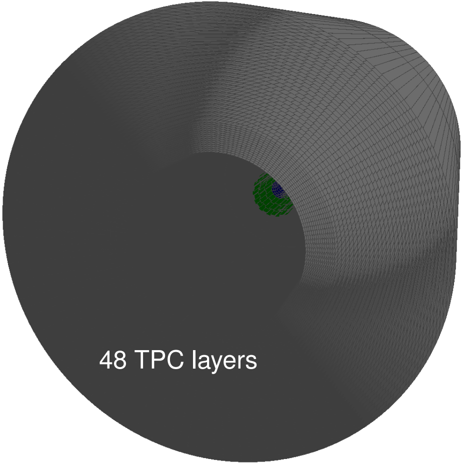
ACTS Geometry - Silicon

- 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 then reflected in ACTS transparently

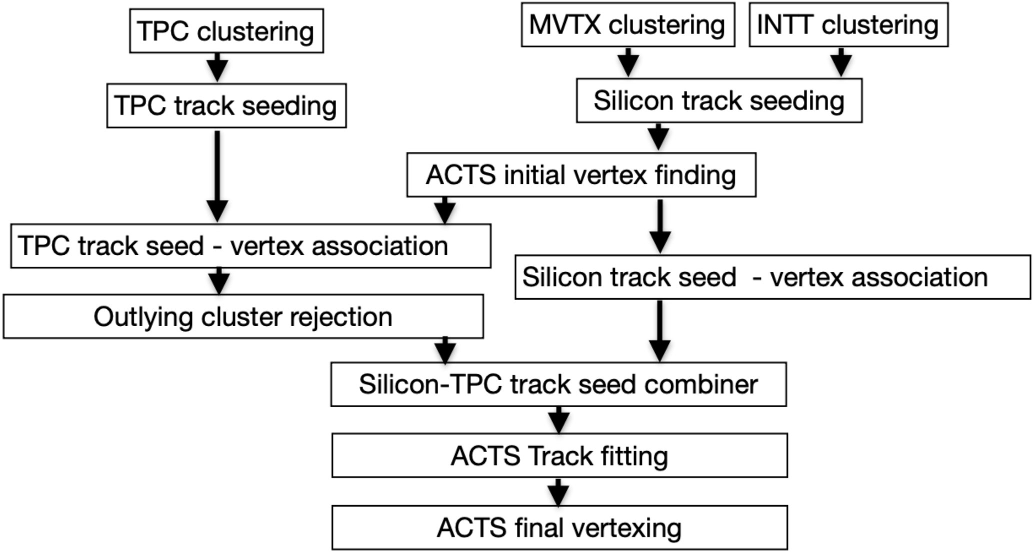


ACTS Geometry - TPC

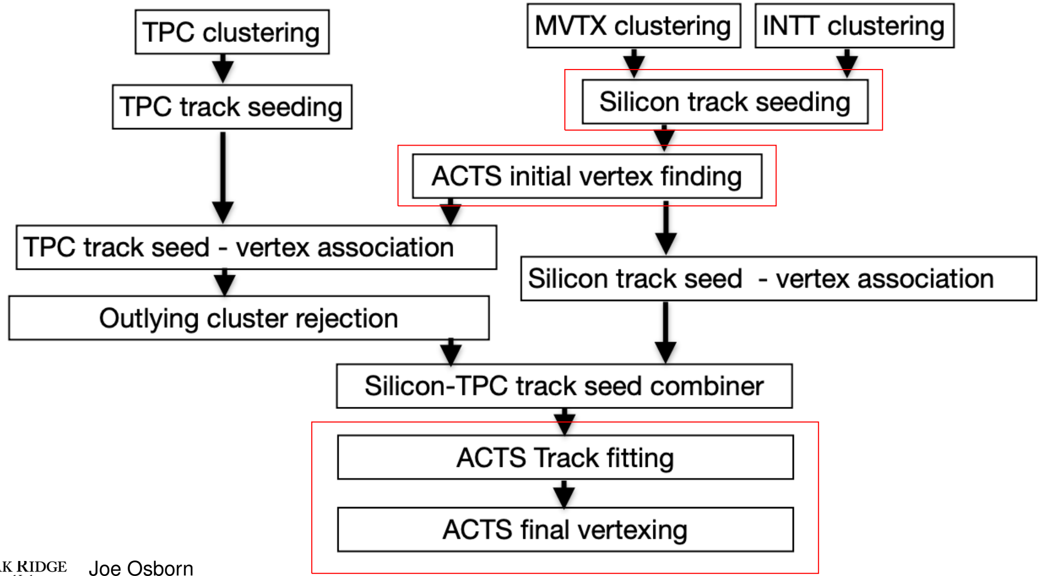
- ACTS geometry model not immediately suited to TPC geometries, since surfaces are required
- With TPC, charge can exist anywhere in 3D volume
  - Side note: ongoing development within ACTS to allow for 3D fitting
- In place, create planar surfaces that mock cylindrical surfaces
- Surfaces are set at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



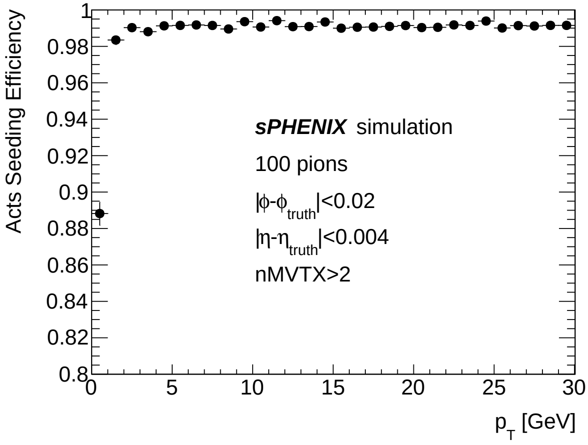
Track Reconstruction Strategy



Track Reconstruction Strategy



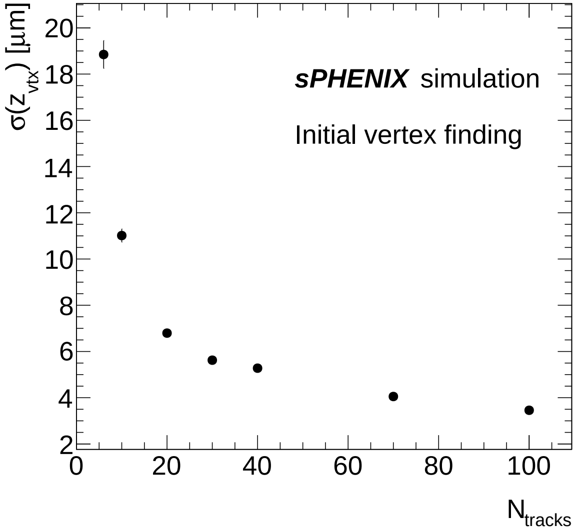
Silicon Seeding



- 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

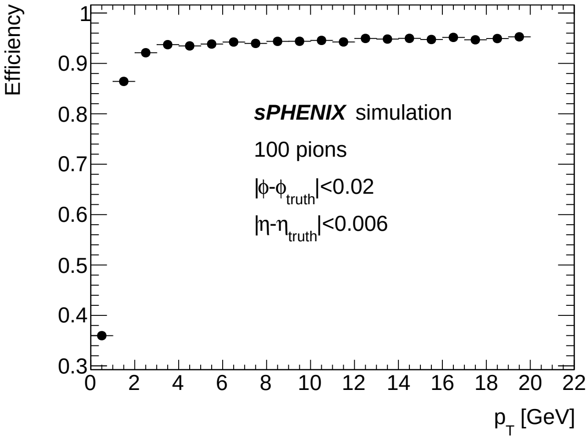
ACTS Vertex Finding

- 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



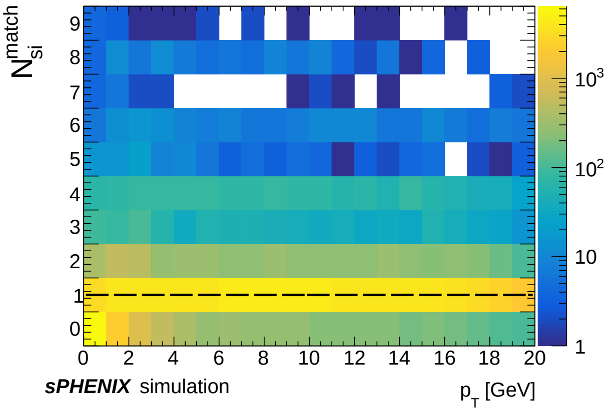
CA Seeding in TPC

- 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



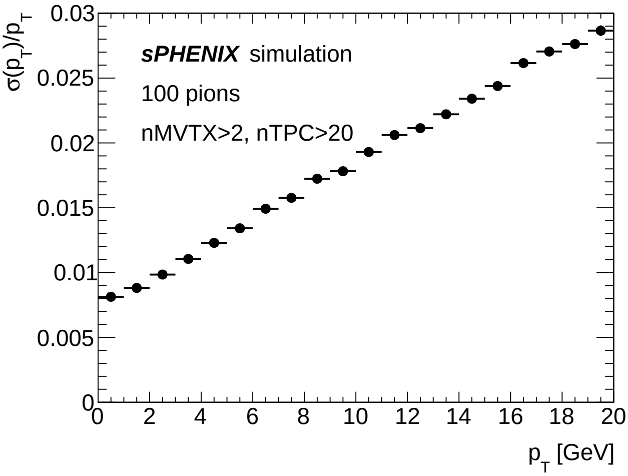
Track Matching

- 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
- Predominantly have 1 silicon tracklet per TPC tracklet. Continuing development to improve multiple matches
- ACTS fitter (next page) is very good at identifying bad seeds in sPHENIX geometry



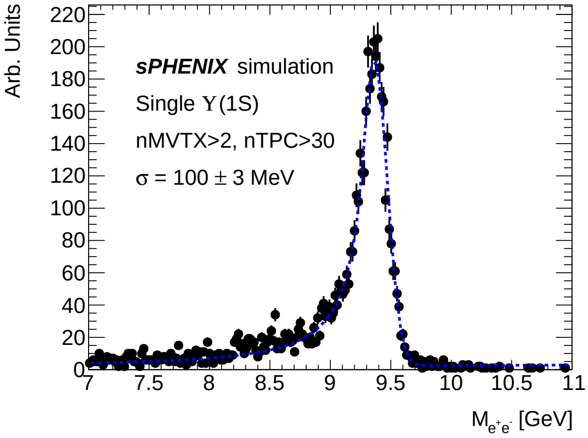
Track Fitting

- Use `Acts::KalmanFitter` tool to fit full assembled track seeds
- Tool performs a full fit outwards, then smooths result inwards to vertex

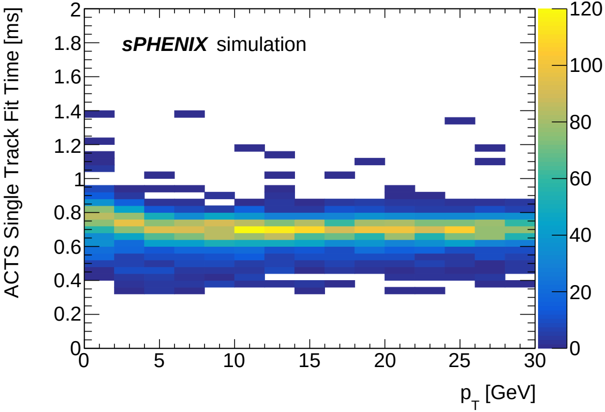


Track Fitting

- Use `Acts::KalmanFitter` tool to fit full assembled track seeds
- Tool performs a full fit outwards, then smooths result inwards to vertex
- Single upsilon mass spectrum meets sPHENIX physics goals
- Continued improvement on TPC seeds expected

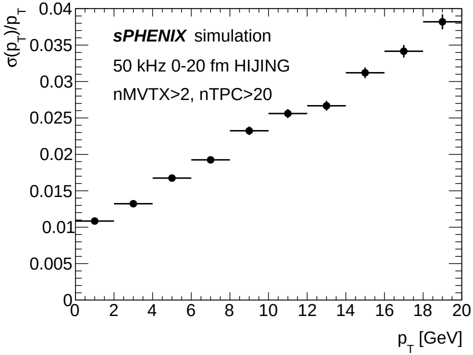


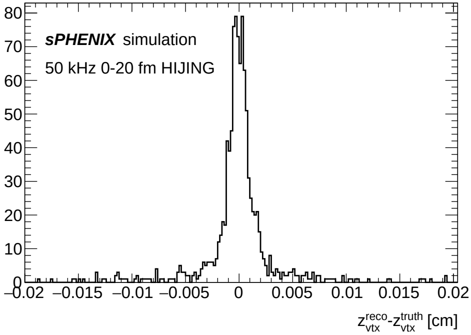
Track Fit Timing



- 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

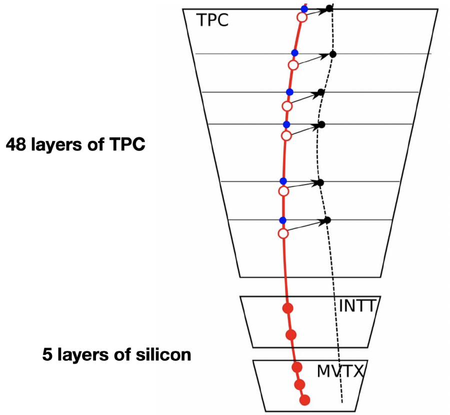
High Occupancy Performance





- 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

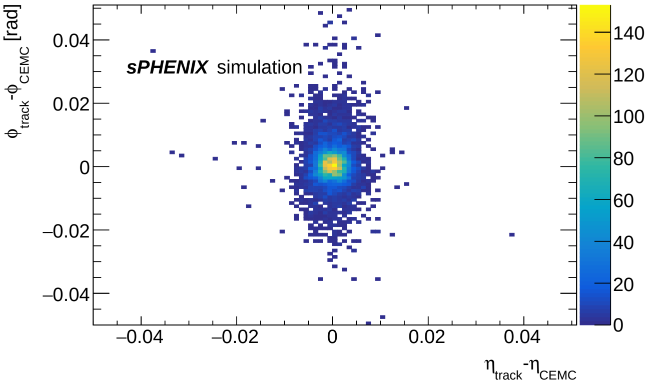
TPC Space Charge Distortions



- 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!