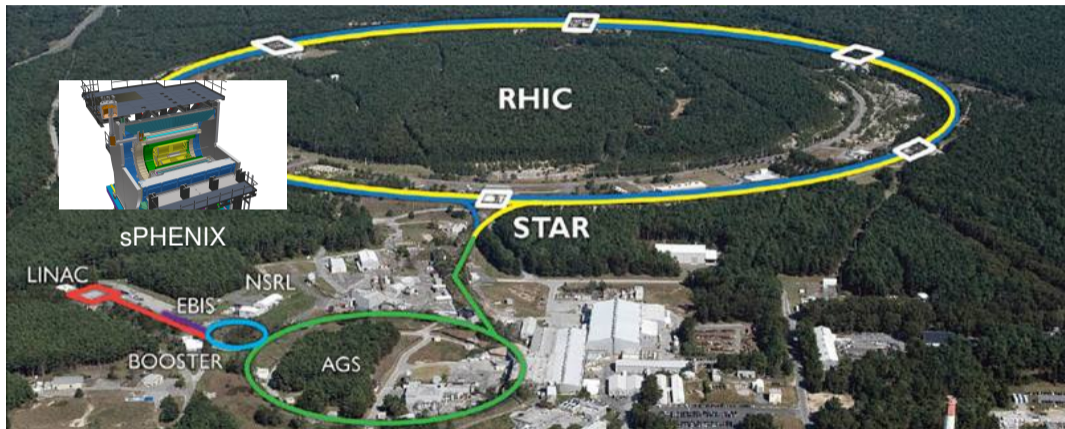


Implementation of ACTS into sPHENIX Track Reconstruction

Joe Osborn
May 17, 2021

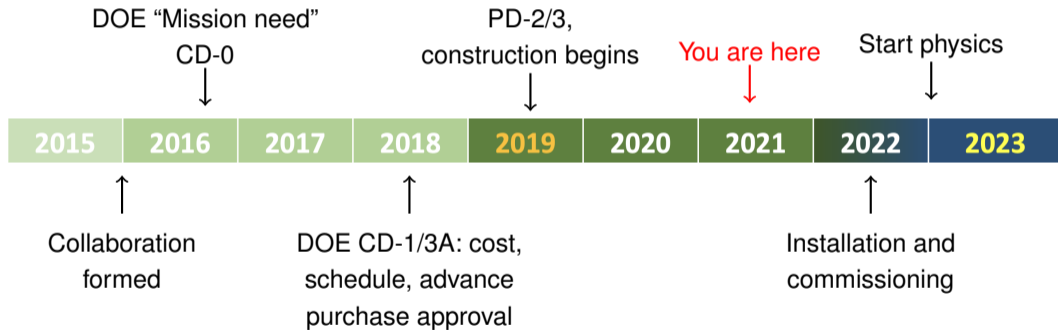
ORNL is managed by UT-Battelle, LLC for the US Department of Energy

Next Generation of QCD at RHIC



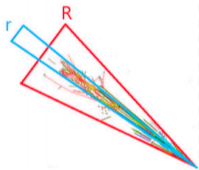
The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory

Collaboration Timeline



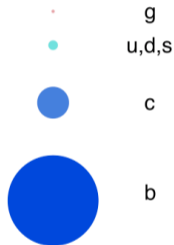
Jet correlation & substructure

Vary momentum/
angular
size of probe



Parton energy loss

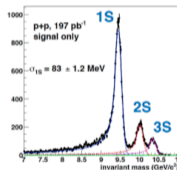
Vary mass/
momentum
of probe



Upsilon spectroscopy

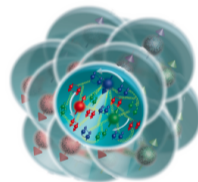
Vary size
of the probe

$Y(3s)$ - 0.78fm $Y(2s)$ - 0.56fm $Y(1s)$ - 0.28fm



Cold QCD

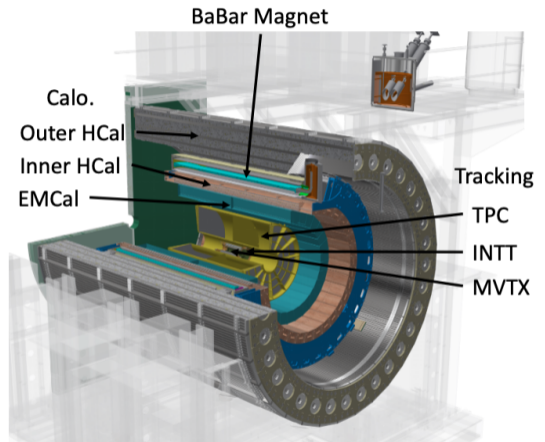
Vary temperature of
QCD matter



- 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 calorimetry (first at RHIC)
 - Large offline data rate of ~ 100 Gbit/s for collecting large minimum bias sample

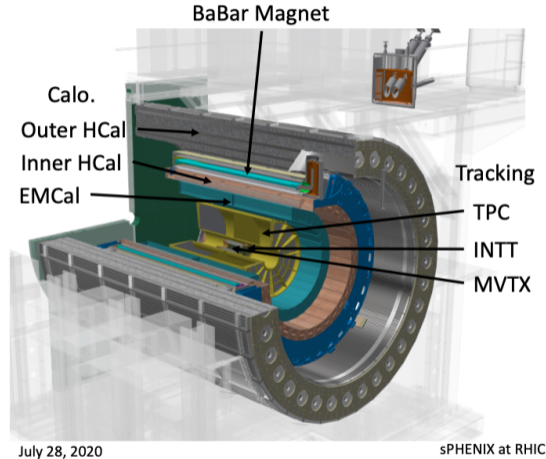


July 28, 2020

sPHENIX at RHIC

sPHENIX Detector

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 - Large, hermetic acceptance
 - Hadronic calorimetry (first at RHIC)
 - Large offline data rate of ~ 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



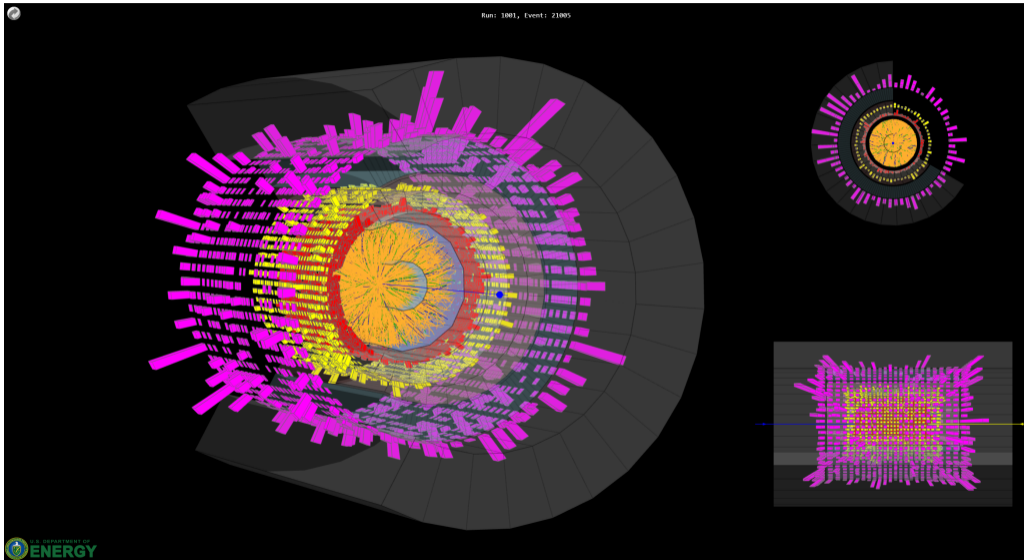
sPHENIX Computing Challenges

- RHIC will deliver Au+Au collisions at 50 kHz, while sPHENIX will record at 15 kHz
- In a 3 year, ~ 24 cryo-week per year data taking campaign, sPHENIX will collect ~ 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

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PB

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- Track reconstruction must be robust to high occupancies from pile up charge

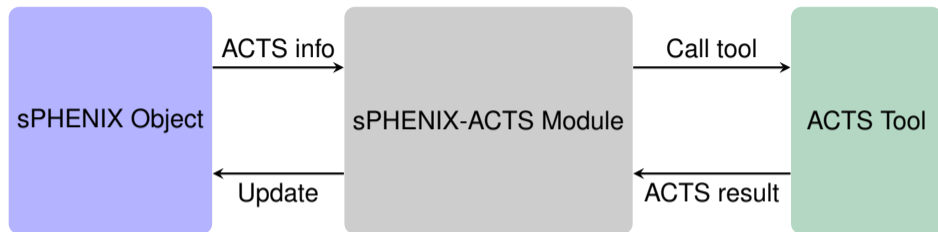
sPHENIX-ACTS Track Reconstruction

- 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
 - ...



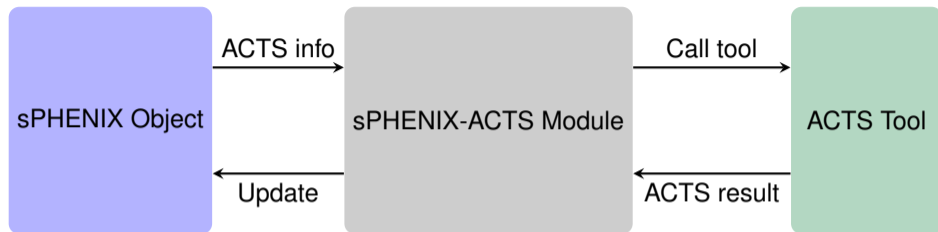
[ACTS Github link](#)

ACTS Implementation Strategy



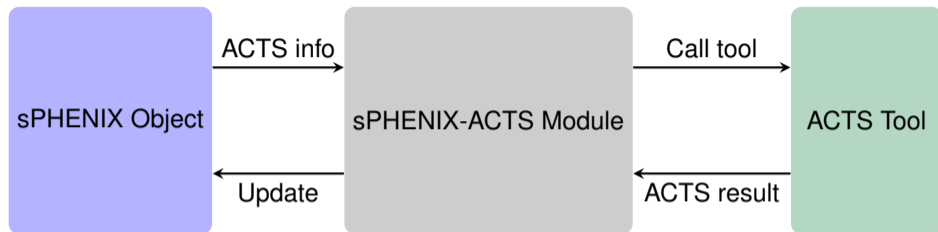
- ACTS requires geometry and measurement objects (that's all)
- sPHENIX objects store necessary information for ACTS objects
- Modules act as wrappers for calling ACTS tools and updating sPHENIX objects

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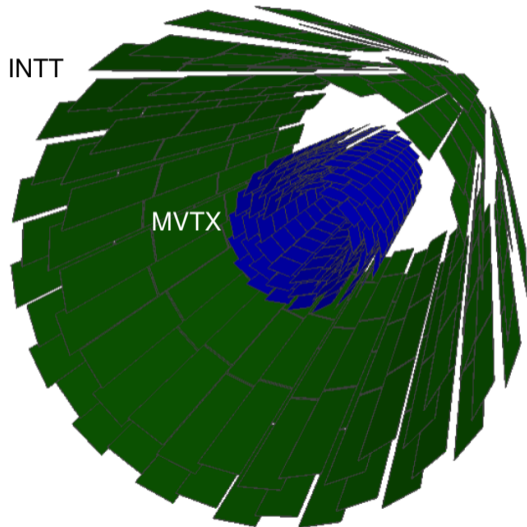
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- Eventually plan to move to a paradigm where sPHENIX objects == ACTS objects, for saving memory and time
- Fun4All-sPHENIX code available on [Github](#) - code is open source and containerized with Singularity. Feel free to ask for more details!

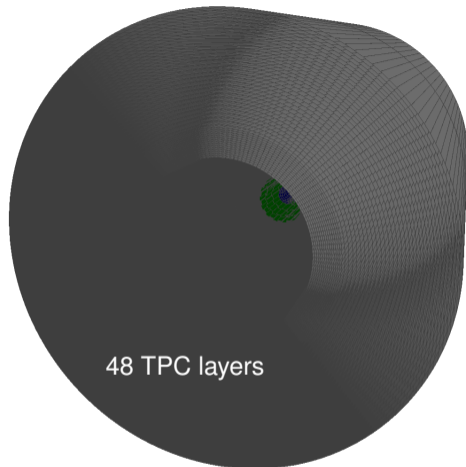
ACTS Geometry - Silicon

- 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

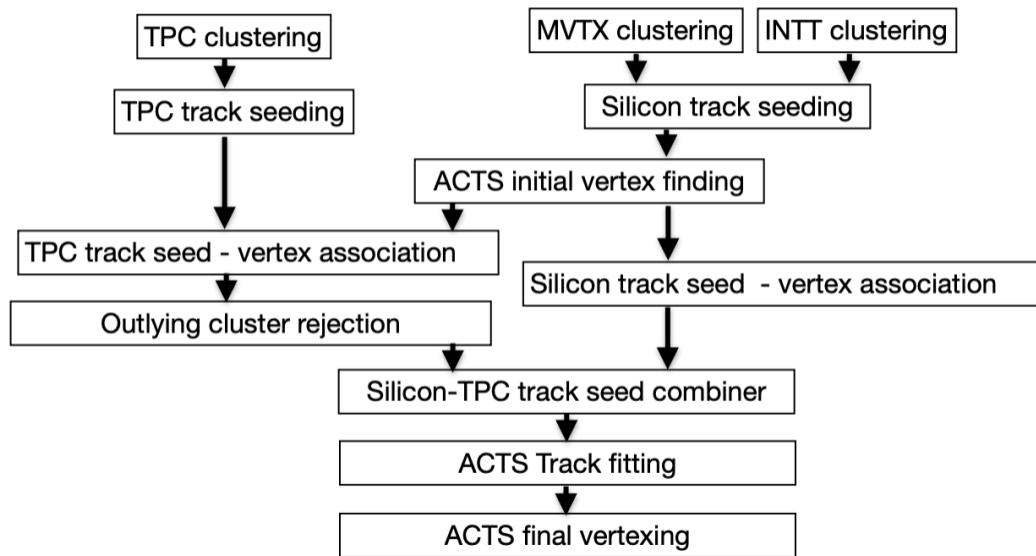


ACTS Geometry - TPC

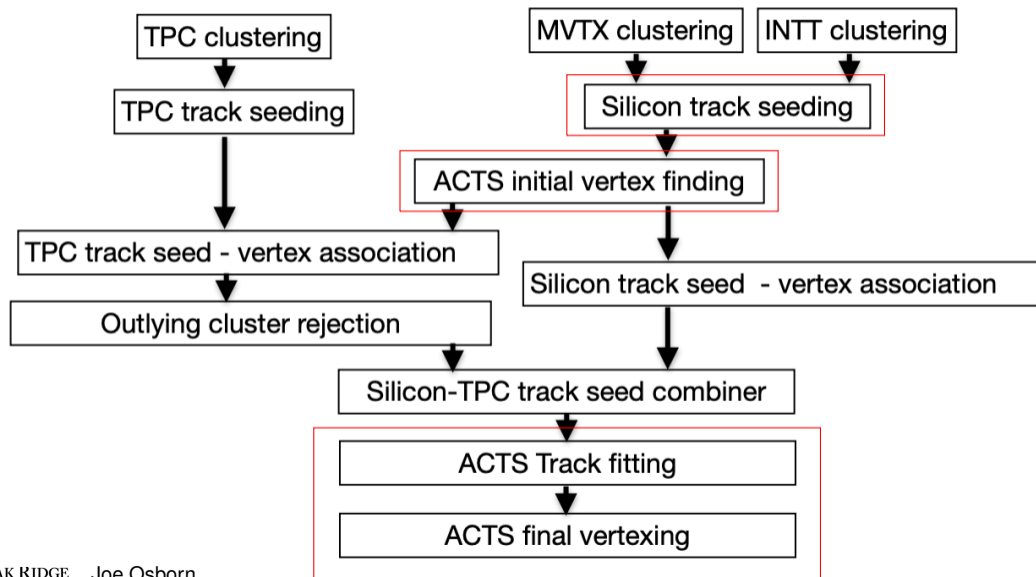
- ACTS geometry model not immediately suited to TPC geometries, since surfaces are required
- With TPC, charge can exist anywhere in 3D volume
 - Side note: ongoing development within ACTS to allow for 3D fitting
- In place, create planar surfaces that mock cylindrical surfaces
- Surfaces are set at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



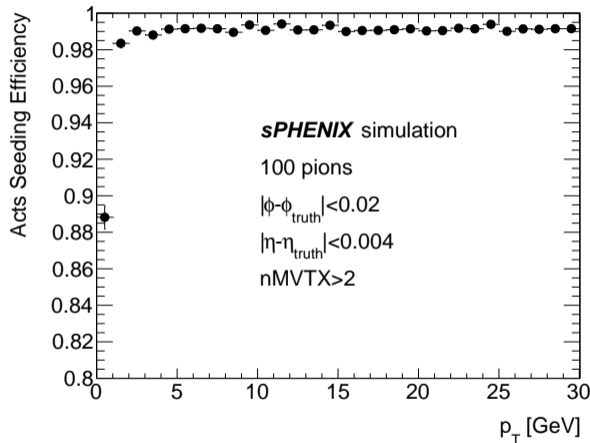
Track Reconstruction Strategy



Track Reconstruction Strategy



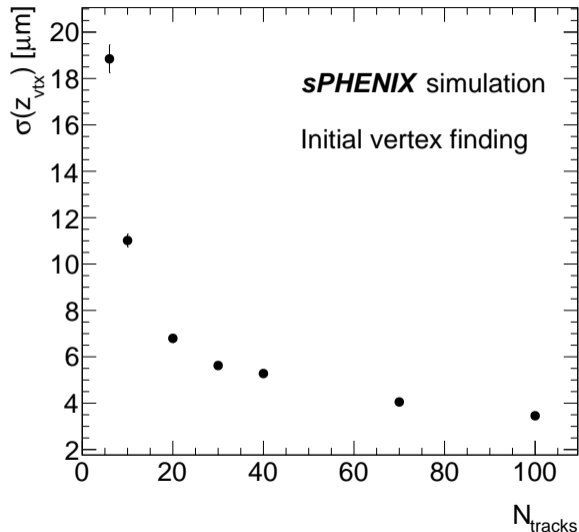
Silicon Seeding



- 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

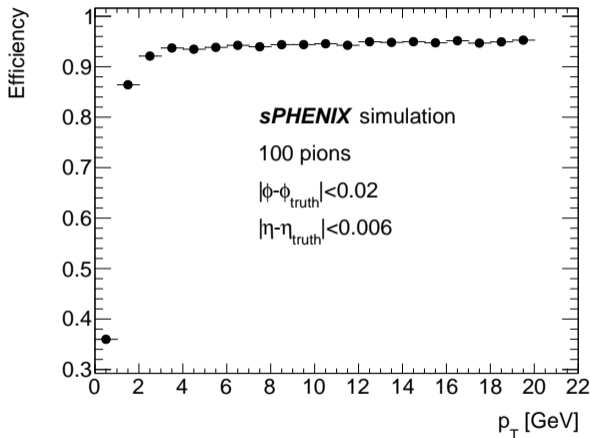
ACTS Vertex Finding

- 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



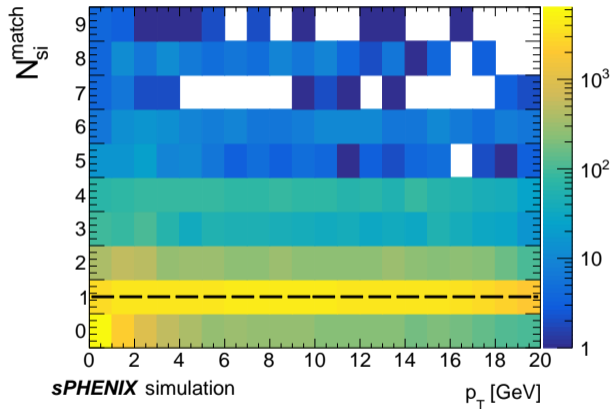
CA Seeding in TPC

- 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



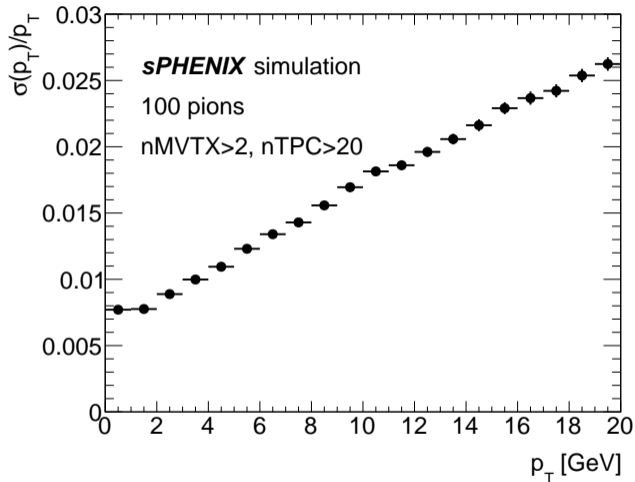
Track Matching

- 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



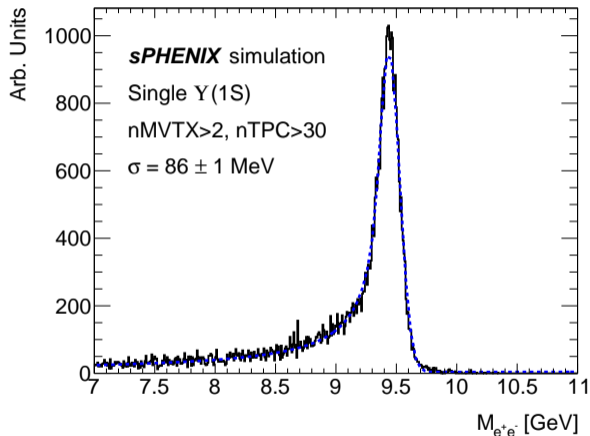
Track Fitting

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

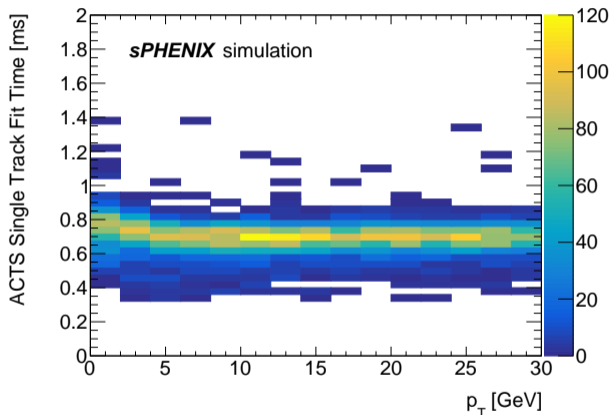


Track Fitting

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

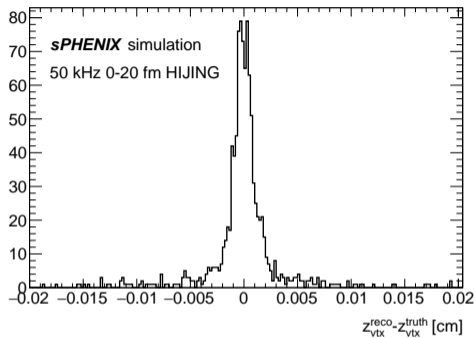
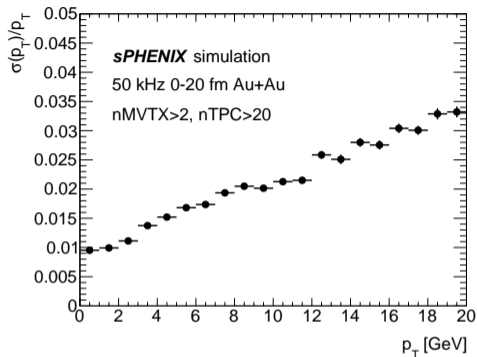


Track Fit Timing



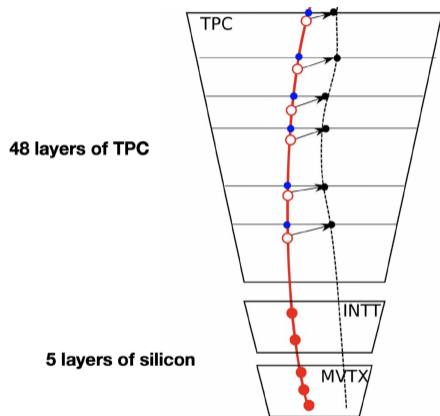
- One of the primary motivations for switching to ACTS was for speed
- `Acts::KalmanFitter` time-per-track is shown here with sPHENIX silicon+TPC geometry
- After ACTS +CA seeding implementation, sPHENIX track reconstruction is $\mathcal{O}(10)$ x faster than previous implementations

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

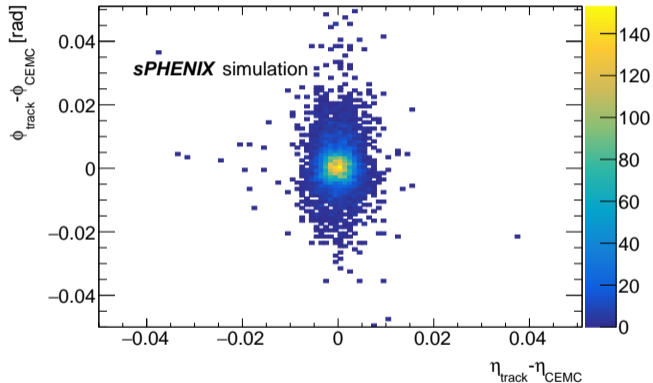
TPC Space Charge Distortions



- 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 accommodate 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!
 - Much more work to be done than what was shown today!