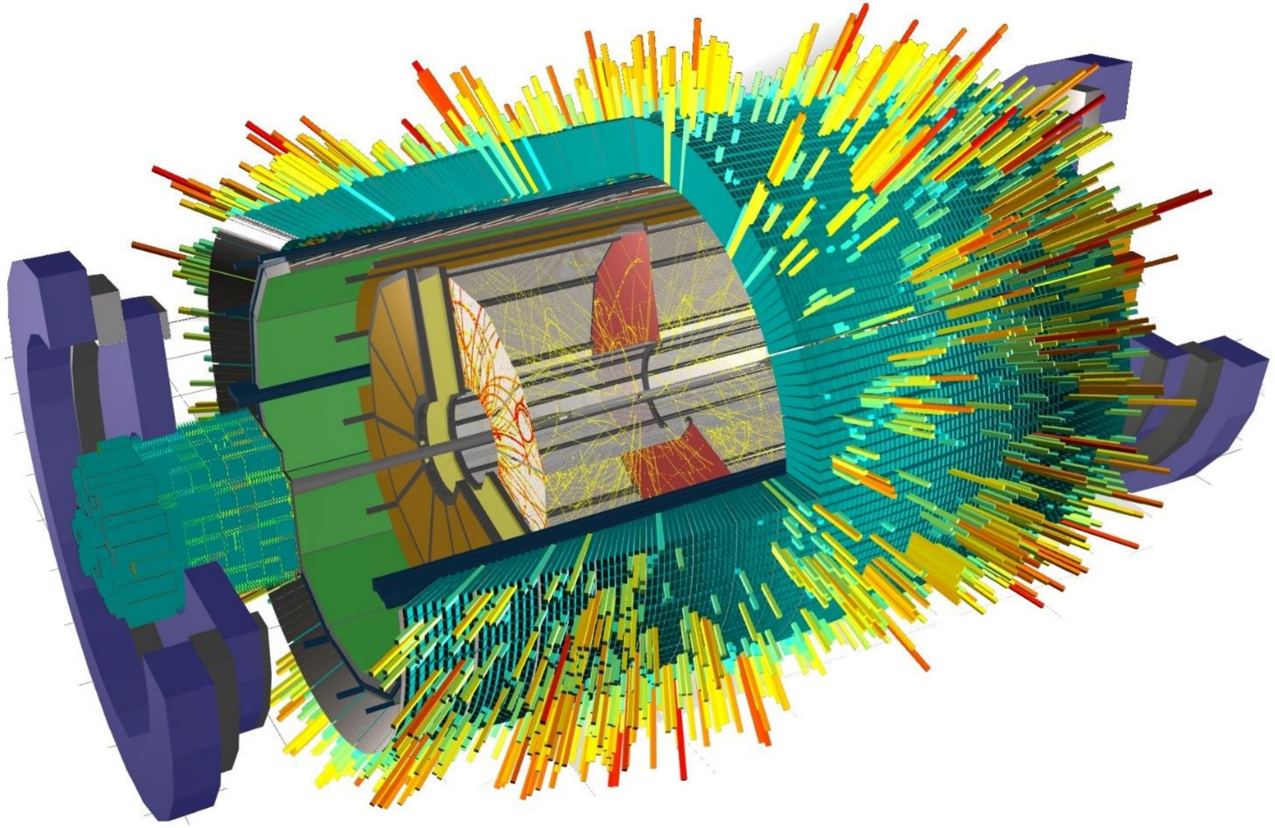
TPC tracking for the MPD Experiment

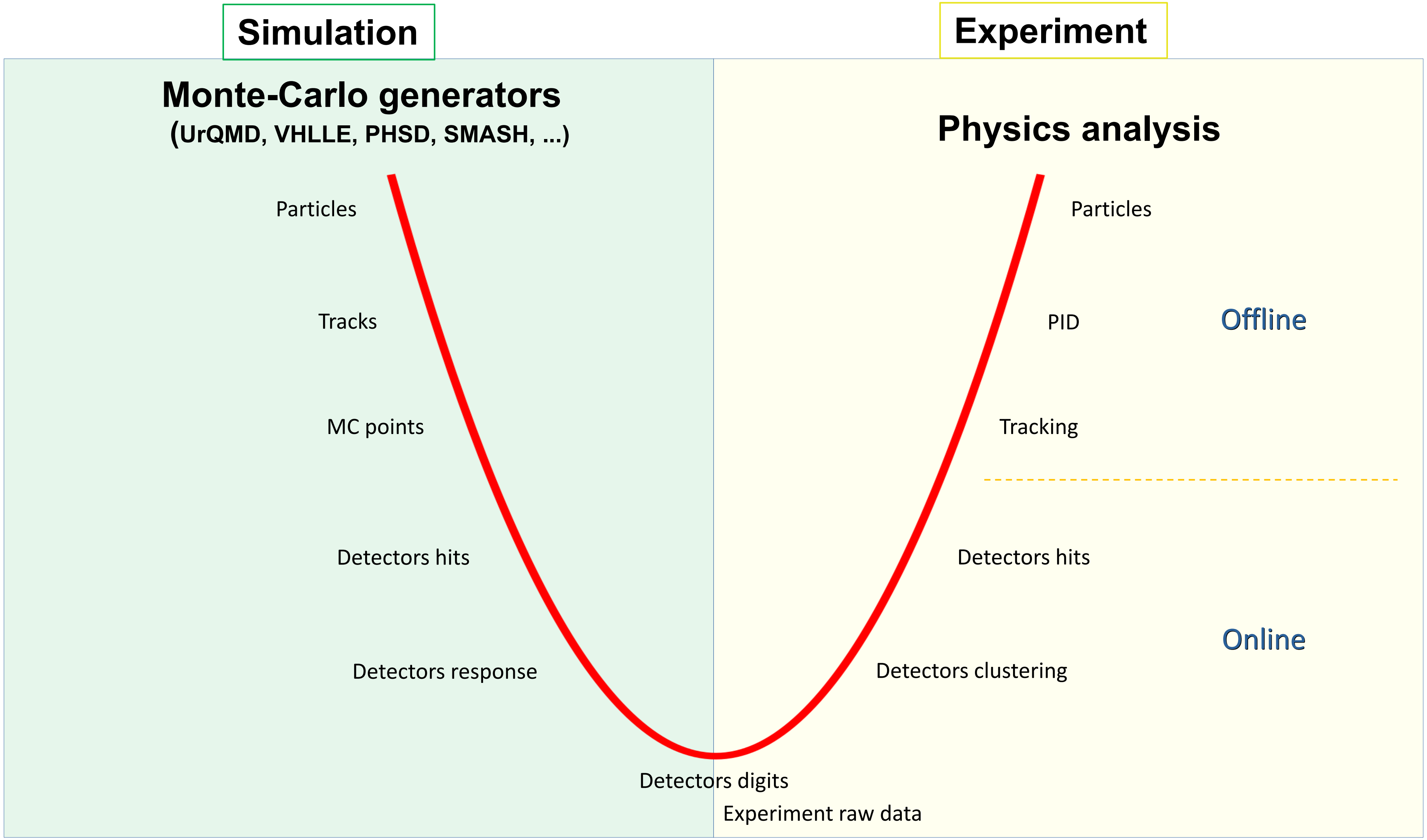
HNATIC Slavomir
on behalf of the
MPD Software Development & Computing Team



OUTLINE

- Big Picture & Goals
- A Common Tracking System (ACTS)
- Development strategy & tools
- Geometry
- Clustering & Hit Extraction
- Benchmarks (preliminary)
- Vertexing
- Present status summary & Future

SIMULATION & EXPERIMENT CHAIN



SOFTWARE & COMPUTING ECOSYSTEM

NICADIST
- separate build system
- dependencies handling

CVMFS
- software distribution
- unified environment

Project Management & Support/User Interaction

GITLAB
- codebase
- CI
- testing

SUPPORT
- helpdesk
- telegram channel

WEBSITE
- howtos
- docs
- general info

R & D

MPDRoot

ANALYSIS

SIMULATION

RECONSTRUCTION

Mass Production

PWG REQUESTS HANDLING

DIRAC INTERWARE

Computing Infrastructure
(MICC & friends)
- supercomputer
- clusters
- storage systems

MPD experiment

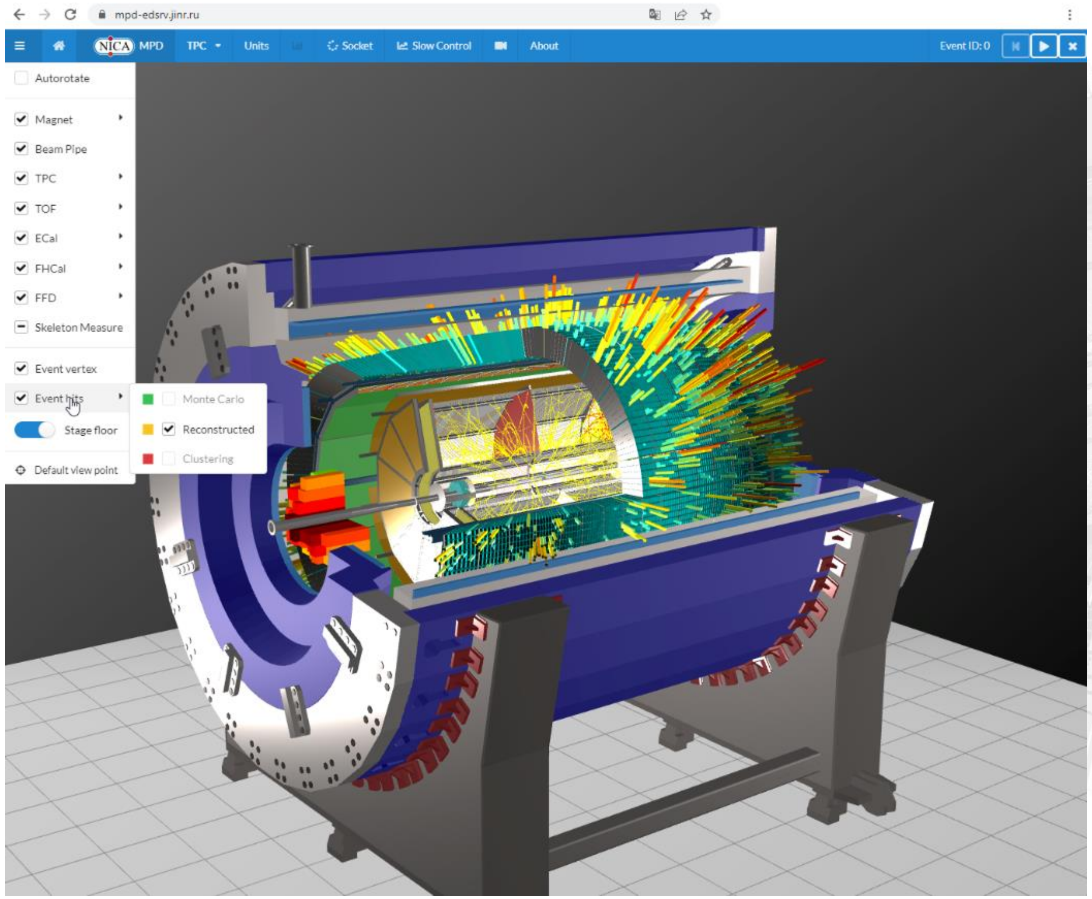
TPC installation: Beginning of 2026

ONLINE EVENT DISPLAY
- experiment visualization
- QA

DETECTOR CALIBRATION
- alignment
- noise level
- digitalization delay
- drift velocity
- trigger latency

DATA
- storage & retrieval
- adjustnment
- clustering

R&D GOALS FOR TPC

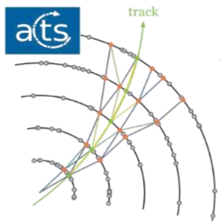


ESSENTIAL OFFLINE FRAMEWORK RECONSTRUCTION OBJECTIVES
(for the real experiment)

- Realistic detector geometry
- Accurate & fast clustering / hit extraction
- Accurate & state-of-art track reconstruction
- Other (electronics simulation, calibration)

- Software requirements - also very important!
- Code quality
- Modern tools & packages
- PM & Maintenance

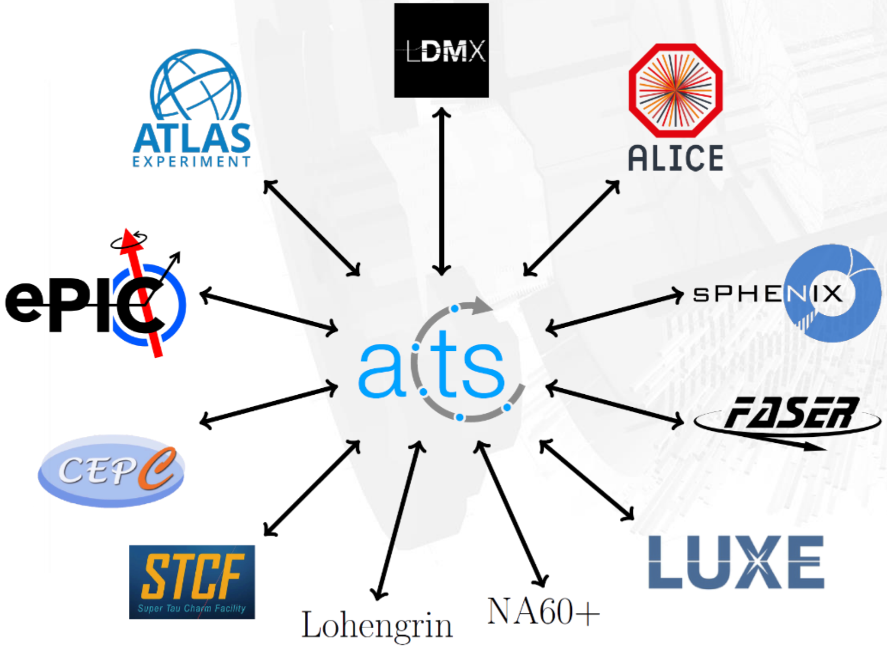
ACTS: A COMMON TRACKING SYSTEM



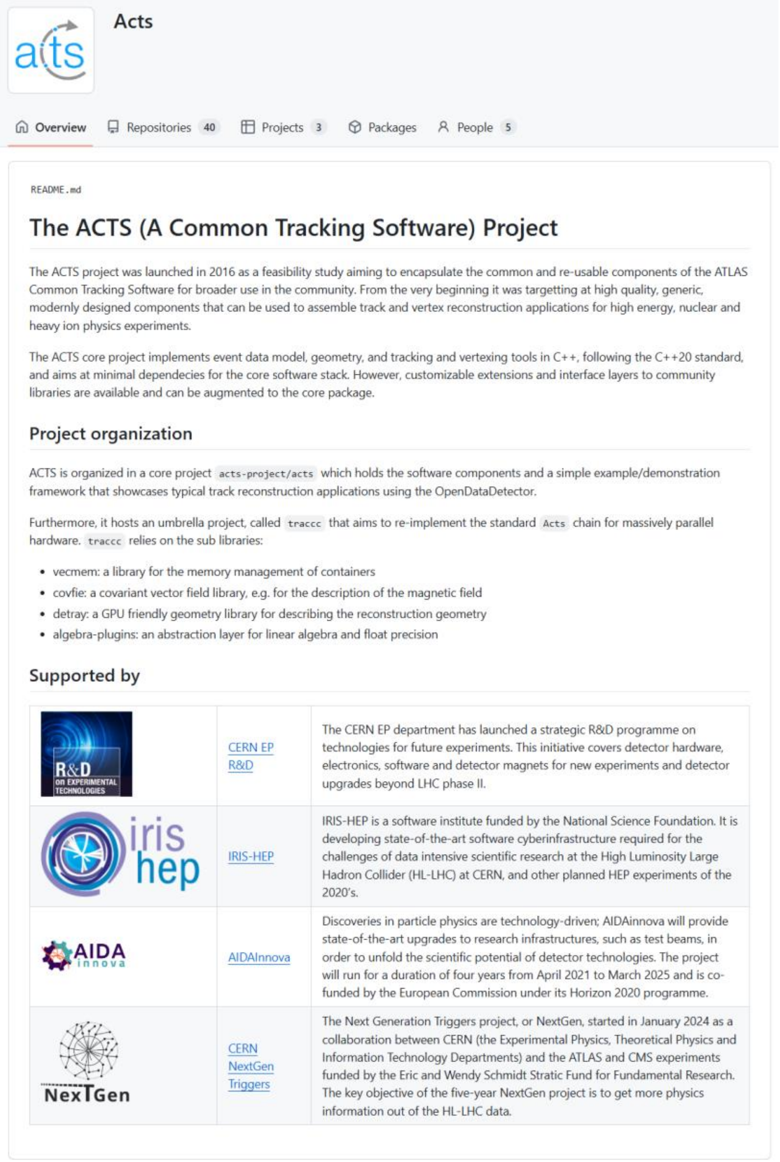
Track Finding with Combinatorial Kalman Filter

- uses KF on multiple branches

Vertex Finding



"The ACTS Project"
A. Salzburger et al.
ACTS for Nuclear Physics, Berkeley, 2025



Acts

Overview | Repositories 40 | Projects 3 | Packages | People 5

README.md

The ACTS (A Common Tracking Software) Project

The ACTS project was launched in 2016 as a feasibility study aiming to encapsulate the common and re-usable components of the ATLAS Common Tracking Software for broader use in the community. From the very beginning it was targetting at high quality, generic, modernly designed components that can be used to assemble track and vertex reconstruction applications for high energy, nuclear and heavy ion physics experiments.

The ACTS core project implements event data model, geometry, and tracking and vertexing tools in C++, following the C++20 standard, and aims at minimal dependecies for the core software stack. However, customizable extensions and interface layers to community libraries are available and can be augmented to the core package.

Project organization

ACTS is organized in a core project `acts-project/acts` which holds the software components and a simple example/demonstration framework that showcases typical track reconstruction applications using the OpenDataDetector.

Furthermore, it hosts an umbrella project, called `traccc` that aims to re-implement the standard `Acts` chain for massively parallel hardware. `traccc` relies on the sub libraries:

- vecmem: a library for the memory management of containers
- covfie: a covariant vector field library, e.g. for the description of the magnetic field
- detray: a GPU friendly geometry library for describing the reconstruction geometry
- algebra-plugins: an abstraction layer for linear algebra and float precision

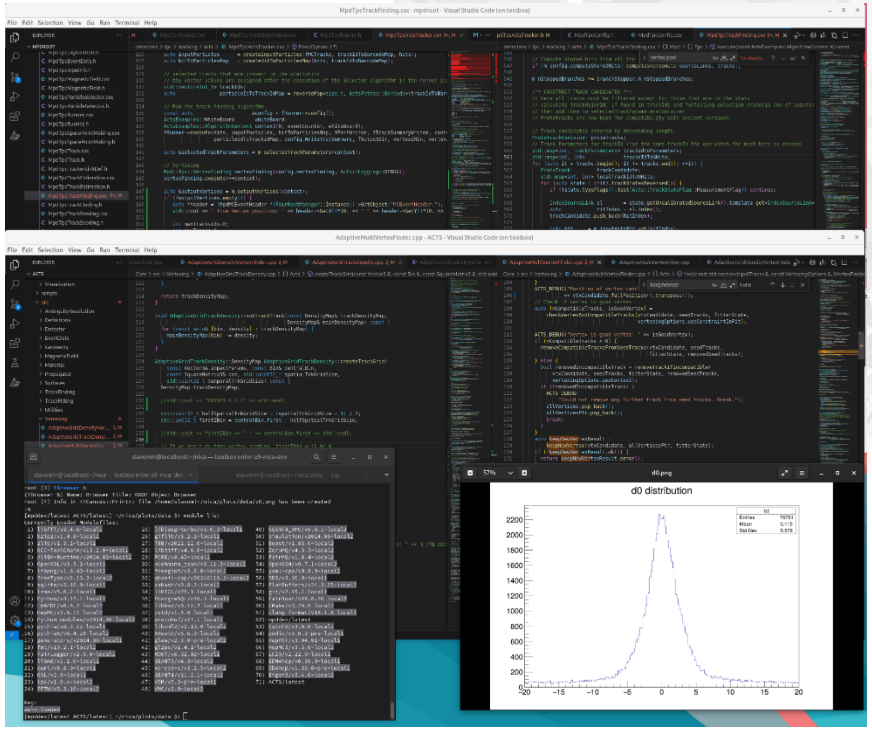
Supported by

R&D on EXPERIMENTAL TECHNOLOGIES	CERN EP R&D	The CERN EP department has launched a strategic R&D programme on technologies for future experiments. This initiative covers detector hardware, electronics, software and detector magnets for new experiments and detector upgrades beyond LHC phase II.
iris hep	IRIS-HEP	IRIS-HEP is a software institute funded by the National Science Foundation. It is developing state-of-the-art software cyberinfrastructure required for the challenges of data intensive scientific research at the High Luminosity Large Hadron Collider (HL-LHC) at CERN, and other planned HEP experiments of the 2020's.
AIDA innova	AIDAInnova	Discoveries in particle physics are technology-driven; AIDAinnova will provide state-of-the-art upgrades to research infrastructures, such as test beams, in order to unfold the scientific potential of detector technologies. The project will run for a duration of four years from April 2021 to March 2025 and is co-funded by the European Commission under its Horizon 2020 programme.
NexTGen	CERN NextGen Triggers	The Next Generation Triggers project, or NextGen, started in January 2024 as a collaboration between CERN (the Experimental Physics, Theoretical Physics and Information Technology Departments) and the ATLAS and CMS experiments funded by the Eric and Wendy Schmidt Stratic Fund for Fundamental Research. The key objective of the five-year NextGen project is to get more physics information out of the HL-LHC data.

DEVELOPMENT STRATEGY & TOOLS

Modularization

- refactoring existing codebase to common API
- runReco.C with switchable modules
- libraries that can be benchmarked against each other
  - TPC clustering / hits extraction
  - TPC tracking



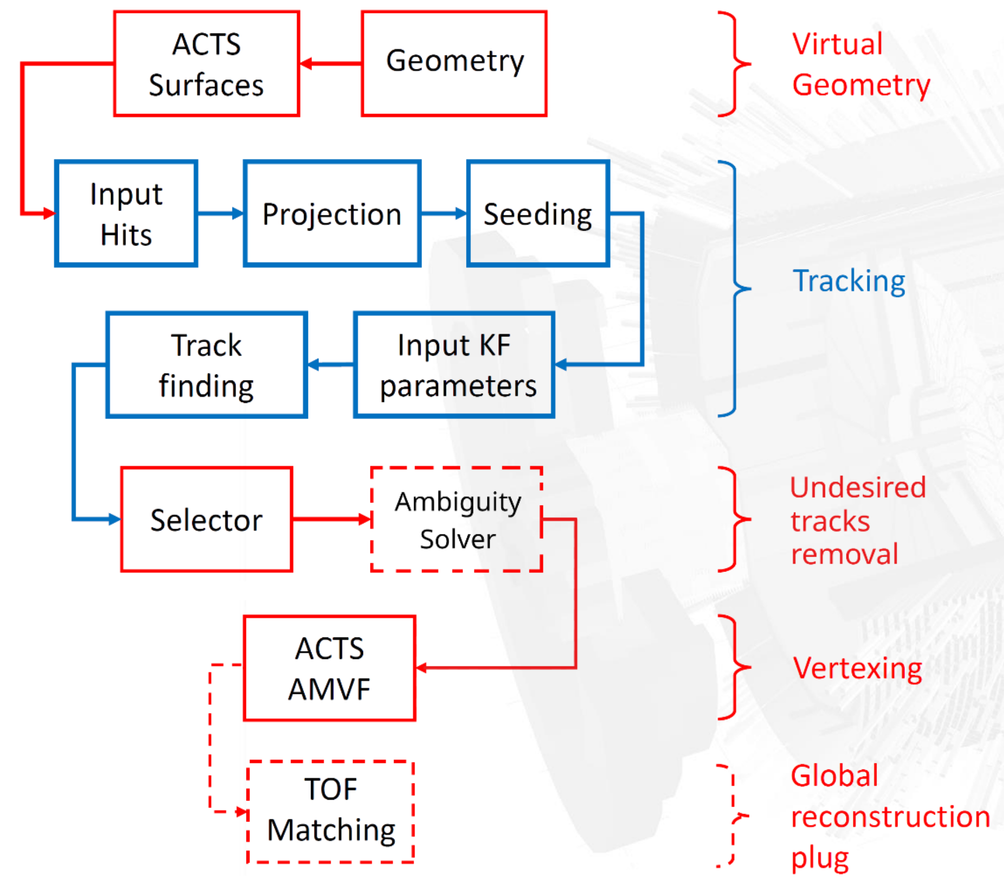
Environment

- Virtual machine with full build (alibuild)
- 71 packages (currently)
- All source codes can be debugged (ACTS, FairRoot, ROOT,….)
- Recompilation intelligently done by alibuild
- Patching dependencies
- Custom features needed for MPD outside of MPDRoot

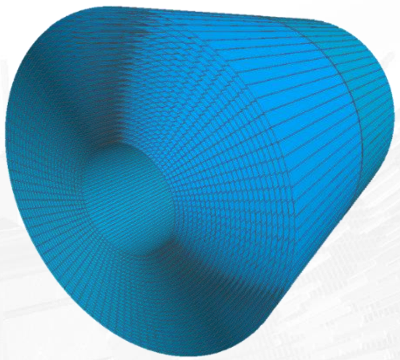
Effective development otherwise impossible

- Lack of documentation
- Overall complexity

ACTS IN MPDROOT



ACTS pipeline in MPDRoot



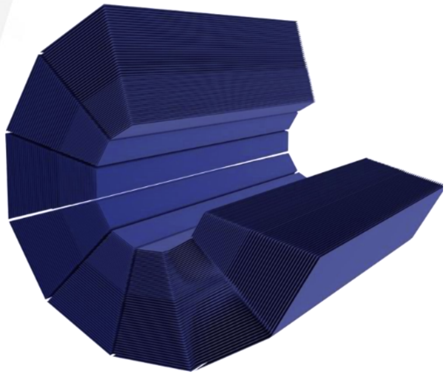
Cylindrical virtual geometry

- Sectors & Layers
- Implemented by parsing the ROOT TGeo geometry and converting the TGeoNode volume into Acts Surface
- heavy, phased out

J.D. Osborn et al.
"Implementation of ACTS into sPHENIX Track Reconstruction."
Computing and Software for Big Science, 2021

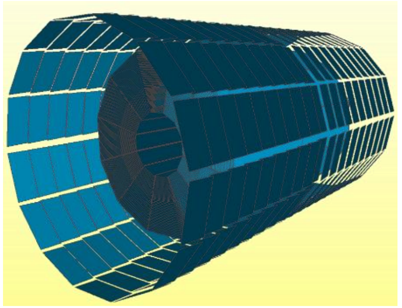
Native MPD TPC geometry

- 24 Sectors & 53 Padrows
- no conversion:
  Volumes & Surfaces are created and glued together directly
- faster, lightweight

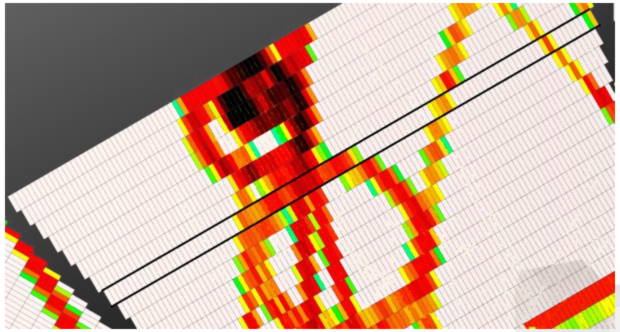


TOF detector added on top of TPC

- ACTS CKF acting in a single space where both TPC and TOF are located
- TOF matching

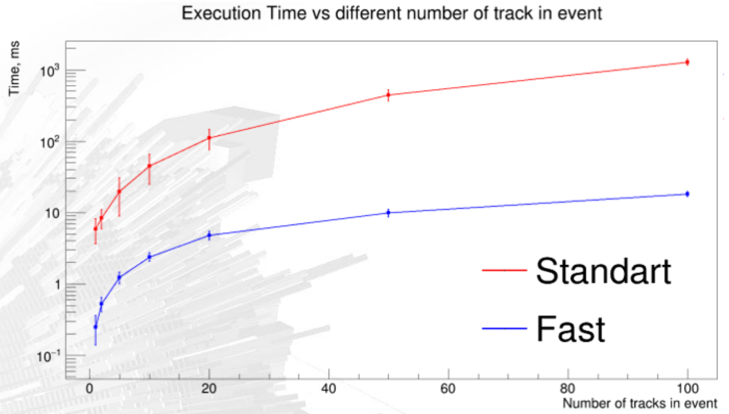


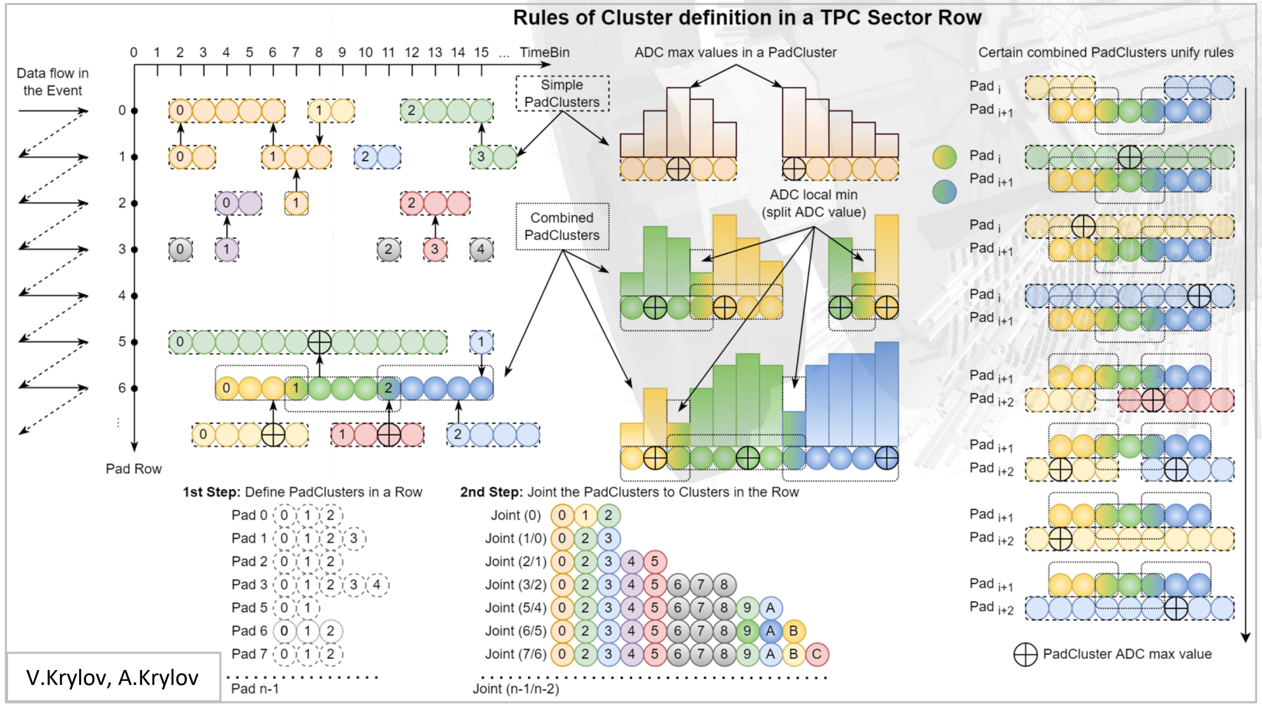
CLUSTERING & HIT EXTRACTION



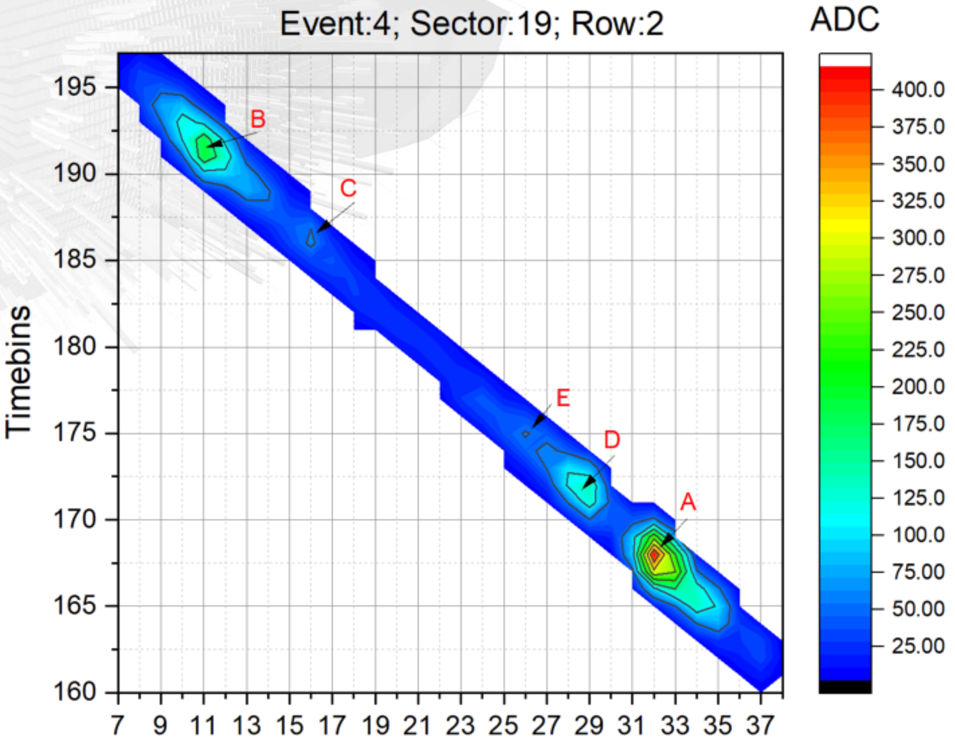
FAST CLUSTERING

- Unique algorithm
- 24 threads (POSIX threads library)
- ~100 times faster than standard clustering !

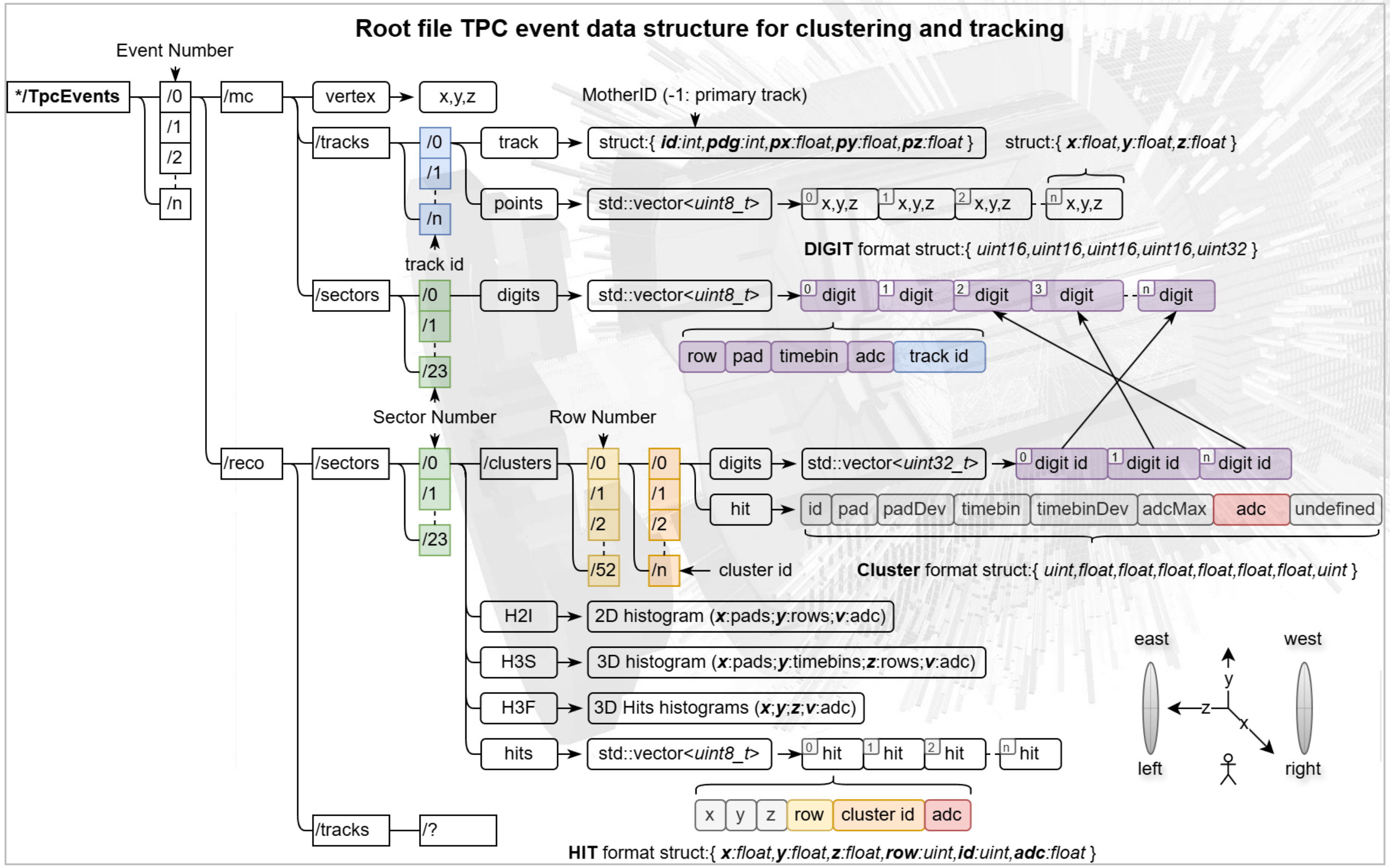




V.Krylov, A.Krylov



INPUT DATA



Experiment

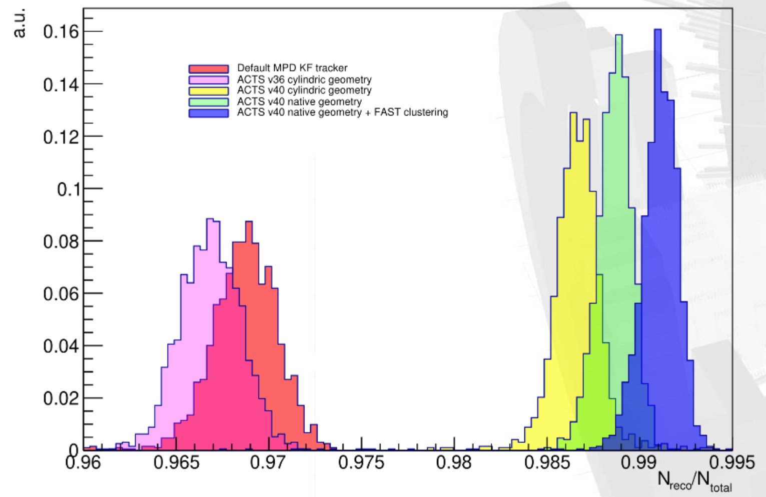
- SAMPA data
- detector calibration parameters
- noise information
- no mc branch

TRACKING EFFICIENCY

CKF enhancements: much better efficiency, far less fakes
Native geometry, Fast clustering: more efficiency improvement

- UrQMD, 200000 events
- 9 minimum hits per track
- P_t > 0.1 GeV

Efficiency



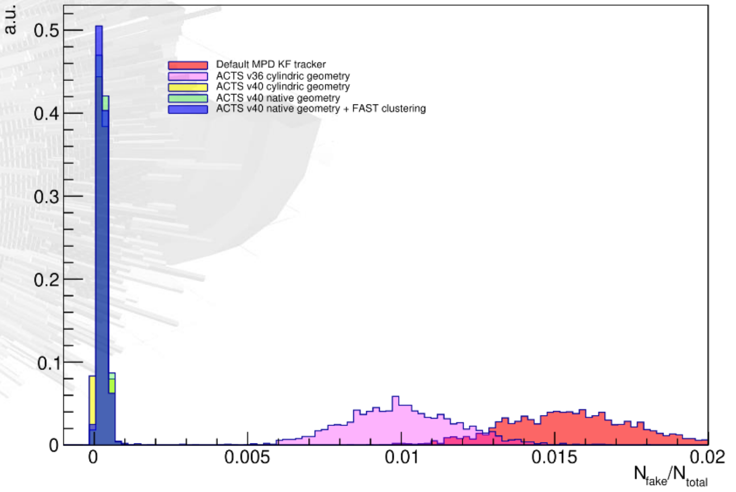
Maximizing efficiency – initial priority

Duplicates to be handled by Ambiguity Solver (not yet implemented), which will *decrease* efficiency

See: A Common Tracking Software Project *Computing and Software for Big Science, X.Ai et al, 2022*

Performance of Track Reconstruction at SCTF Using Acts, *EPJ Conferences, X.Ai et al, 2024*

Fake rate

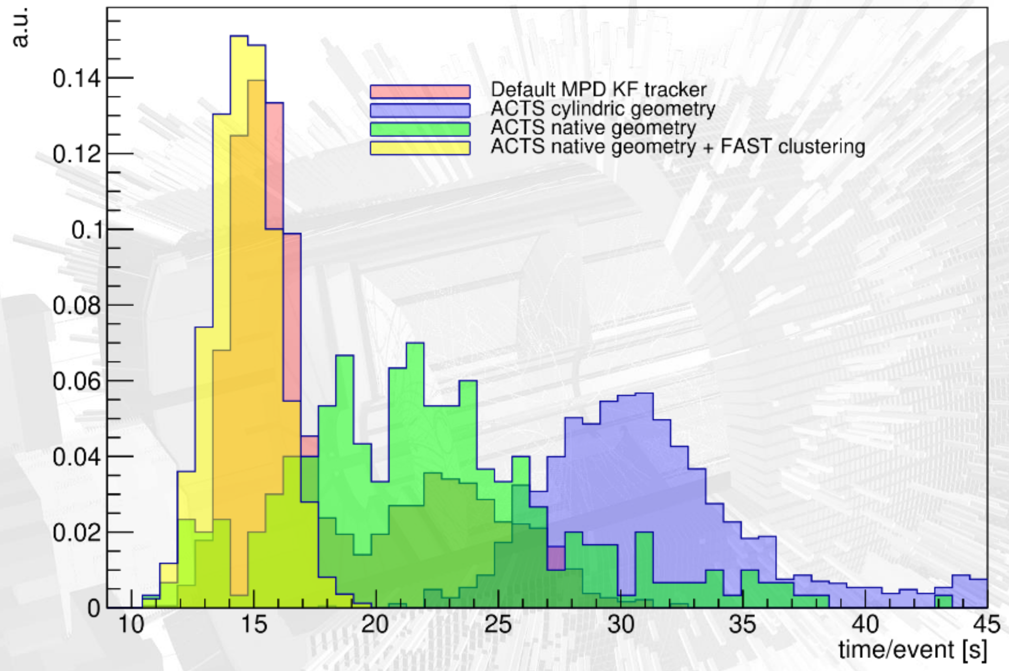


	Default tracker		ACTS v36 cylindric		ACTS v40 cylindric		ACTS v40 native		ACTS v40 native + Fast	
	true rate	fake rate	true rate	fake rate	true rate	fake rate	true rate	fake rate	true rate	fake rate
BiBi 9.2 GeV	$\mu = 0.9686$ $\sigma = 0.00212$	$\mu = 0.01544$ $\sigma = 0.002012$	$\mu = 0.9668$ $\sigma = 0.001724$	$\mu = 0.00999$ $\sigma = 0.00189$	$\mu = 0.9866$ $\sigma = 0.001779$	$\mu = 0.00026$ $\sigma = 0.000172$	$\mu = 0.9886$ $\sigma = 0.000922$	$\mu = 0.000275$ $\sigma = 0.000140$	$\mu = 0.991$ $\sigma = 0.000973$	$\mu = 0.000261$ $\sigma = 0.000136$

"Implementation of ACTS into MPDRoot"
S. Hnatic, J. Busa Jr., A. Bychkov, A. Krylov, V. Krylov, A. Moshkin, O.Rogachevsky

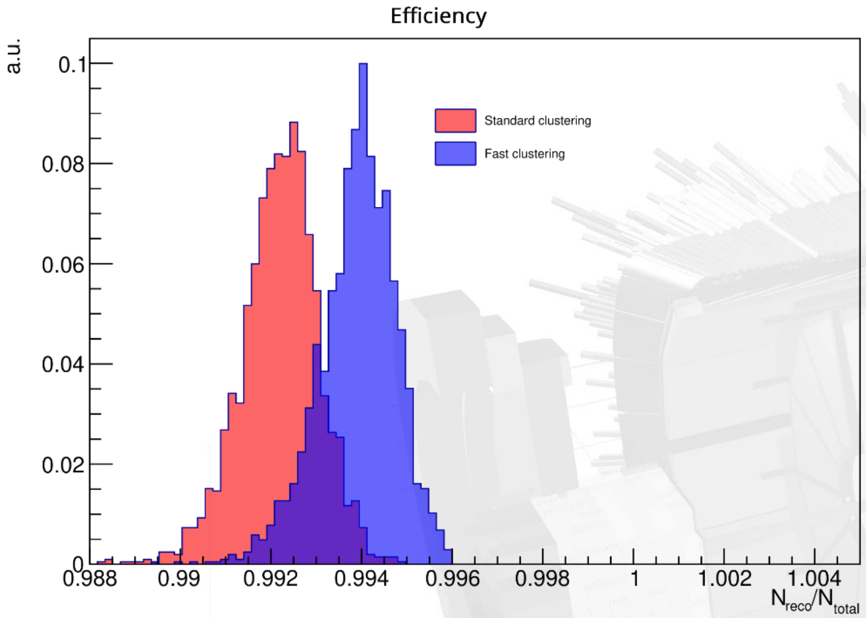
MMCP '24 Proceedings, PEPAN

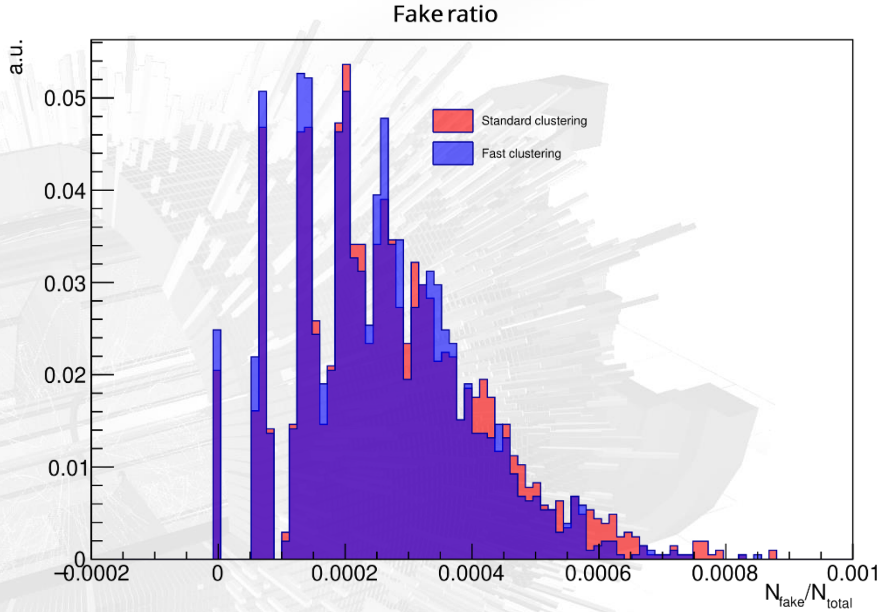
TRACKING SPEED

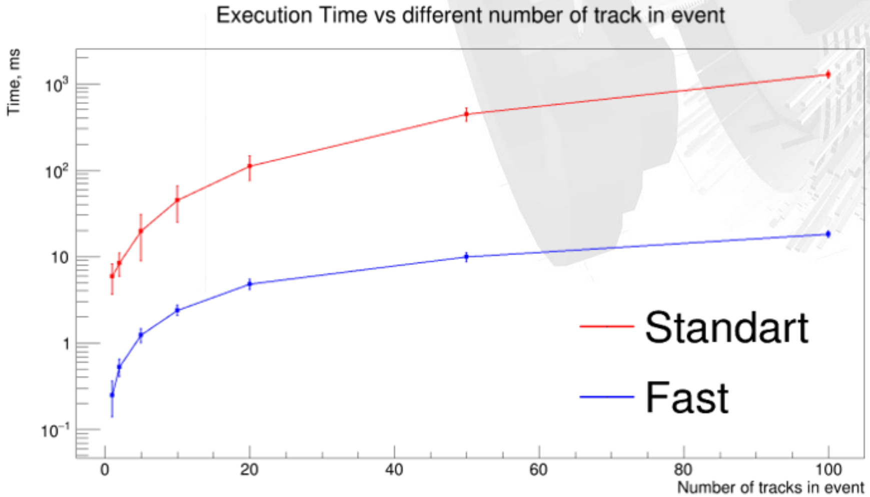


STANDARD + DEFAULT KF	μ = 18.12 s / event	σ = 4.28 s / event
STANDARD + ACTS cylindric geometry	μ = 31.12 s / event	σ = 2.27 s / event
STANDARD + ACTS native geometry	μ = 21.95 s / event	σ = 5.60 s / event
FAST + ACTS native geometry	μ = 15.09 s / event	σ = 1.42 s / event

CLUSTERING COMPARISON



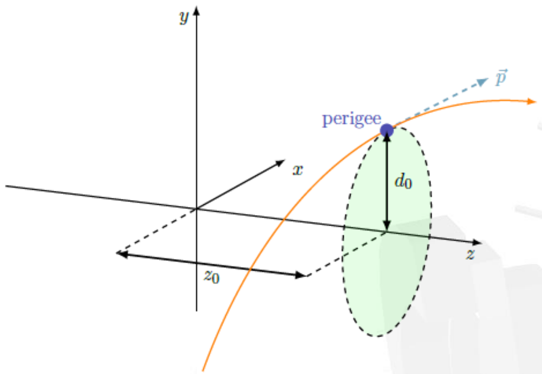




Preliminary tests

- better efficiency
- comparable fake ratio
- ~100 times faster
- extracts ~20% more hits
- better memory management
- clean code
- room for improvement

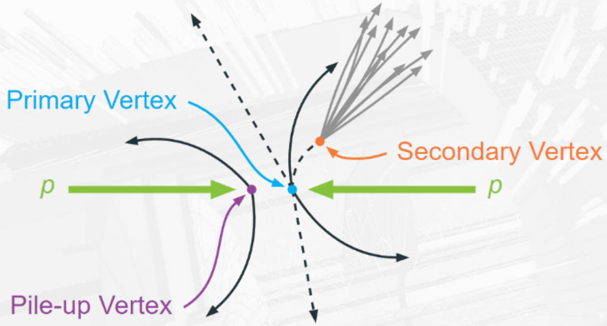
ACTS PRIMARY VERTEXING



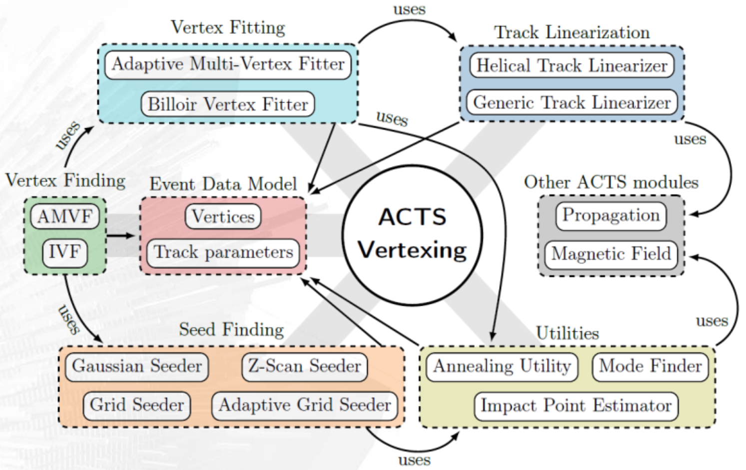
PERIGEE TRACK PARAMETRIZATION

Track selection: |d_0| < 2mm

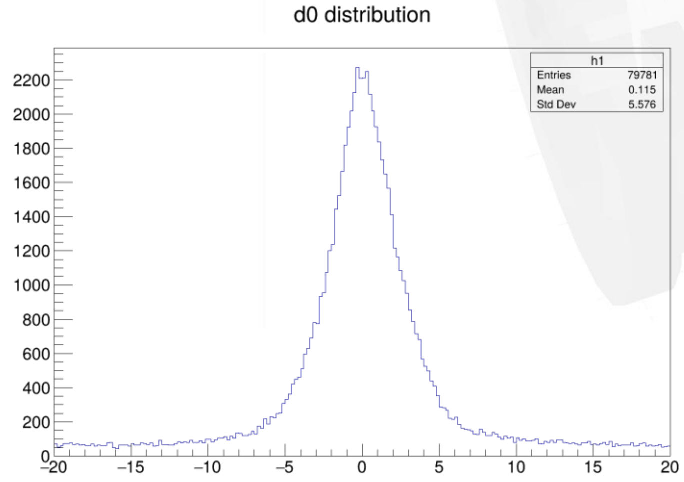
ACTS VERTEXING SUITE



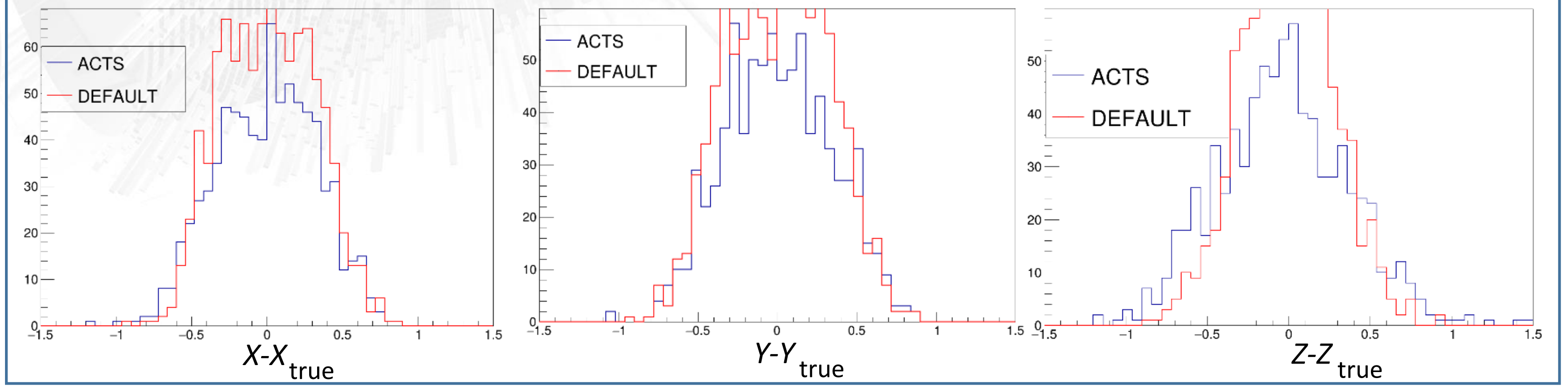
- many tunable parameters



Schlag S. “Advanced algorithms and software for primary vertex reconstruction and search for flavor-violating supersymmetry with the ATLAS experiment.” Dissertation, Johannes Guttenberg-Universitaet Mainz, 2022.



1000 events, BOX generator



TPC TRACKING SUMMARY & FUTURE

TRACKING

- ACTS implementation written for MPD
- Continuously upgraded
- Native geometry written
- Clustering replacement written & integrated
- Preliminary results comparable with ACTS papers

IN PROGRESS / TBD

- Global integration (current focus)
- Ambiguity solver (high priority)
- Vertexing tuneup
- Overall tracker tuneup
- Lot of work !

MPD Software Development & Computing Team

Rogachevsky O. .... Coordinator

Krylov V. .... Clustering, Microservices

Krylov A. .... MPD Event Display

Bychkov A. .... Detector Simulation

Kuzmin V. .... Detector Alignment

Moshkin A., Pelevanyuk I. .... Distributed Computing

Alexandrov E., Alexandrov I. .... Databases

Busa J. .... Build System

Hnatic S. .... Architecture, Tracking

Acknowledgements to MLIT JINR, VBLHEP JINR

Thank You !

Q & A