A Common Tracking Software (ACTS) Implementation in MPDRoot

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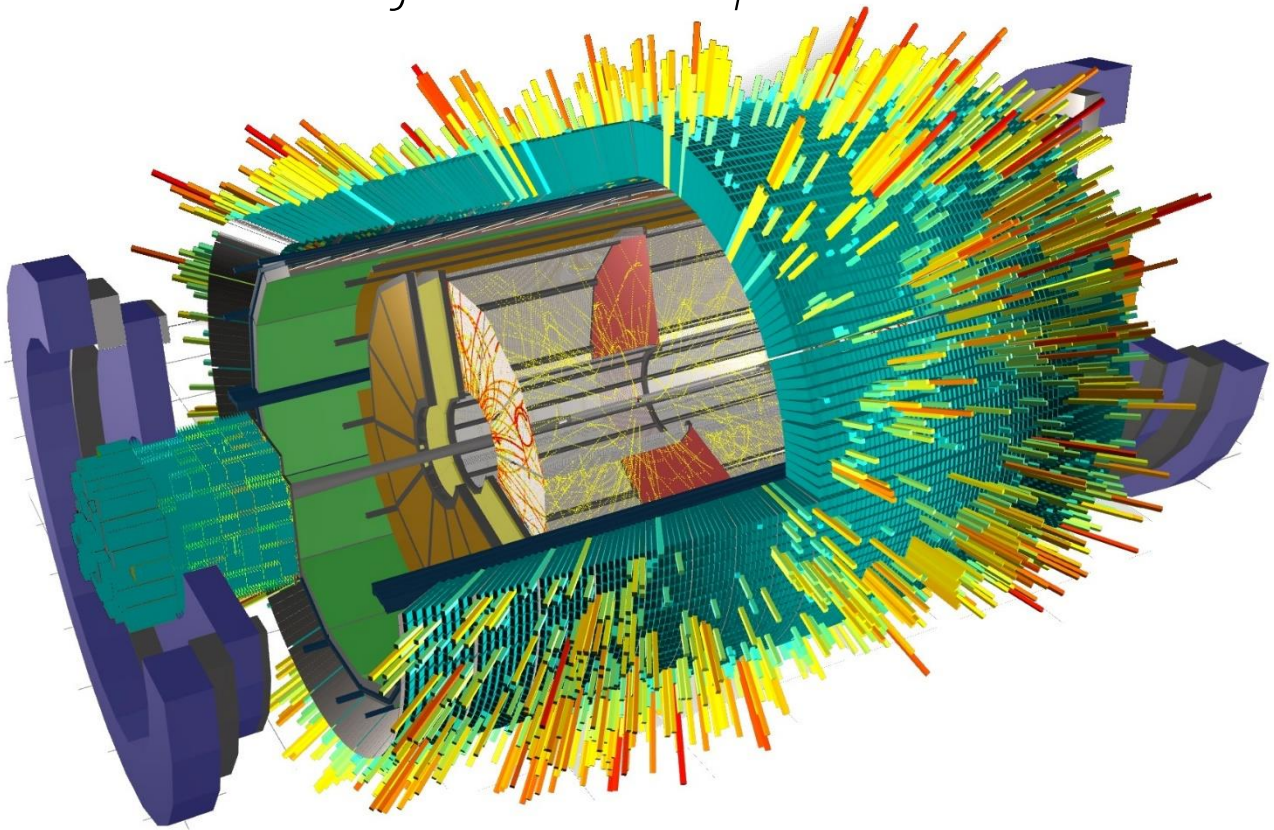
MPD Software Development Team



OUTLINE

- Quick Recap
- Software Development summary
- ACTS framework
- Continuous migration scope
- ACTS Vertexing in MPDRoot
- Track selection
- Preliminary results
- Full ACTS Vertexing suite
- Remaining tasks, future perspectives

QUICK RECAP (April 2024)

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 assembly

TPC installation: March/May 2025

ONLINE EVENT DISPLAY
- experiment visualization
- slow control

DATA STORAGE & RETRIEVAL

DETECTOR CALIBRATION
- alignment
- noise level
- digitalization delay

RELEASES SINCE APRIL 2024

MOST IMPORTANT CHANGES

New features

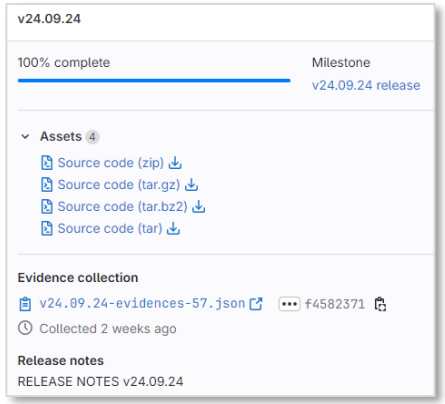
- Analysis updates (physicists)
- LUSI detector
- Global QA histograms
- ACTS vertexing
- ACTS v36 port

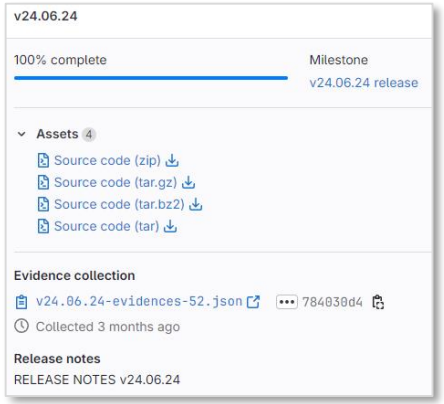
Latest dependencies

- ROOT …… 6.32.06
- GCC ……13.2.0
- Boost …….1.83.0
- FairRoot …. 18.6.10
- GEANT4 …. 11.2.1
- Python …… 3.12.4
- GSL ……2.8
- Fedora 40, Ubuntu 24.04 LTS

DETAILED INFO in RELEASE NOTES

git.jinr.ru/nica/mpdroot/-/releases





Important fixes

- GEANT4 working with ACTS
- Nonzero Z vertex working with ACTS

ACTS TRACKER

CORE CONCEPTS

- Modern C++
- Thread-safe design
- Experiment independent core component and algorithmic implementations
- Virtual inheritance (run time polymorphism) minimized, compile time polymorphism used (templates)
- Customizable configuration struct
- Abstraction from experimental details (generic EDM, geometry)
- Transparent handling of experiment context
- Algorithmic modules – stateless engines

```
// Example ACTS algorithm
class Algorithm {
public:
  // Nested configuration struct
  struct Config {
    int configVariableA = 0;
    double configVariableB = 0.;
  };

  // Nested state struct
  struct State
  {
    int cachedValue = 0;
  };

  // Construct the algorithm from its configuration
  Algorithm(const Config& cfg);

  // ‘const‘ method requiring or modifying cached information
  void doSomething(State& state) const;

private:
  // The configuration object
  Config m_cfg;
};
```

CONTINUOUS MIGRATION SCOPE

Example: ACTS v36.0.0 (July 2024) → v37.0.0 (October 2024)

https://github.com/acts-project/acts/releases (changelogs)

🚀 Features

- Memory dense `MeasurementContainer` for Examples (#3528) by @andiwand
- Detray geometry/material conversion in examples (#3579) by @asalzburger
- Allow user to supply root branch to Core CKF (#3534) by @andiwand
- Add counters to propagation summary (#3602) by @asalzburger
- Generalized conversion of FullPhysicalVolume (#3585) by @Berggren-Jonas
- Broadcast dataflow check to python (#3624) by @asalzburger
- Improvements to multitrajectory iterators (#3619) by @stephenswat
- *(util)* Add GraphViz helper types (#3635) by @paulgessinger
- Allow digitization to save cells (#3626) by @stephenswat
- Add Detray surface grid converter (#3608) by @asalzburger
- Add measurement emplace functions (#3627) by @stephenswat
- Added new SVG functionality (#3649) by @asalzburger
- 🚨 **BREAKING**: Track-EDM like implementation for the space points, to be used in the se
- Allow detray sterile/non-sterile propagation (#3652) by @asalzburger
- Support seed from N space points (#3645) by @CarloVarni
- Enable geant4 propagation xcheck (#3657) by @asalzburger
- Adding possibility to read flat surface container (#3668) by @asalzburger
- *(geo)* TrackingVolume gets portal storage (#3673) by @paulgessinger
- *(geo)* TrackingVolume gets surface storage (#3675) by @paulgessinger
- Allow volume constrain for propagation (#3470) by @andiwand
- *(geo)* Extent designated initialization (#3680) by @paulgessinger
- 🚨 **BREAKING**: (fix + chore) streamline nSegments usage (#3419) by @asalzburger
- Allow Style setting for IndexedSurfaceGrid in Svg (#3686) by @asalzburger
- Add test for space point edm (#3690) by @CarloVarni
- Gen 3 portal shells (#3564) by @paulgessinger
- 🚨 **BREAKING**: Add a radius bin to the grid (#3662) by @CarloVarni
- Add support for Timed Clusterization (#3654) by @CarloVarni
- New material comparison script (#3389) by @asalzburger
- Make vertexing in Examples more configurable (#3406) by @andiwand
- Implement modified Bryson–Frazier (mBF) smoother as alternative to `GainMatrixSmoother` (
- Add `TrackProxy::shallowCopy` (#3428) by @paulgessinger
- `TruthVertexSeeder` for Examples (#3364) by @andiwand
- Adding sympy stepper to python bindings (#3433) by @asalzburger
- Reverse track finding for Examples (#3200) by @andiwand
- Prototracks-to-Tracks converter & refactor (#3357) by @benjaminhuth
- Use track particle double matching by default in Examples (#3409) by @andiwand
- Splitting fill and update function (#3465) by @asalzburger
- Add CMake presets (#3135) by @andiwand
- Decouple SurfaceAccessor from source link implementations (#3445) by @ssdetlab
- *(util)* Grid type-erased output and comparisons (#3469) by @paulgessinger
- Variable size measurement for Examples (#3107) by @andiwand
- Change propagation algorithm to particle gun input (#3462) by @asalzburger
- *(geometry)* `RegularSurface` gets direction-less `isOnSurface` (#3500) by @paulgessinger
- Refactor and generalize propagation validation (#3514) by @asalzburger
- Add GeoModel to G4 detector construction helper (#3530) by @benjaminhuth
- Bind some Gen1 geometry building functionality to python (#3448) by @benjaminhuth
- Telescope style seeding (#3300) by @ssdetlab
- GeoModelDetectorObjectFactory for flexible conversion of GeoModel objects to Acts Surfa
  @Berggren-Jonas
- *(geo)* `Surface::isOnSurface` gets tolerance parameter (#3544) by @paulgessinger
- Max chi2 for outliers in Core `MeasurementSelector` (#3475) by @andiwand
- *(geo)* Add name setter and move constructor to `TrackingVolume` (#3542) by @paulgessing
- Add displaced vertex generator (#3446) by @AichaMattouhi
- Renavigation for Gen1 (#3437) by @andiwand
- *(geo)* Gen3 portal links (#3531) by @paulgessinger
- Add B-field accessors to Python bindings (#3554) by @stephenswat
- Detray material conversion (#3546) by @asalzburger
- Add covfie magnetic field plugin (#3479) by @stephenswat
- Gen3 geometry Portals (#3501) by @paulgessinger
- Adding unit tests for `DetrayGeometryConverter` and `DetrayMaterialConverter` (#3572) b
- Introduce navigation stream (#3538) by @asalzburger
- Hashing seeding algorithm (#3148) by @CouthuresJeremy
- *(gx2f)* Material effects - multiple scattering (#3292) by @AJPfleger
- Allow Core CKF to skip the start surface (#3535) by @andiwand
- GeoModel conversion for TGC, sTGC and MicroMega (#3540) by @Berggren-Jonas

CONTINUOUS MIGRATION SCOPE

Example: ACTS v36.0.0 (July 2024) → v37.0.0 (October 2024)

https://github.com/acts-project/acts/releases (changelogs)

🚚 Refactor

- Write smoothed states in GX2F (#3584) by @andiwand
- 🚨 **BREAKING**: Remove `Utilities/detail/Subspace.hpp` (#3589) by @andiwand
- Rework tracklet handling in Examples track finding (#3587) by @andiwand
- 🚨 **BREAKING**: Template algorithms on track container frontend `TrackContainer` (#3193) by @andiwand
- 🚨 **BREAKING**: Remove `EventData/TrackHelpers.hpp` (#3588) by @andiwand
- Write unbiased states only for smoothed in `RootTrackStatesWriter` (#3561) by @andiwand
- 🚨 **BREAKING**: Remove deprecated API (#3591) by @andiwand
- Volume holds bounds as mutable (#3595) by @paulgessinger
- 🚨 **BREAKING**: Path handling to use `std::filesystem` (#3308) by @AJPfleger
- 🚨 **BREAKING**: Replace `EigenStepper` extension list with single extension (#2865) by @andiwand
- Replace `Acts::min_max` with `std::ranges::minmax_element` (#3601) by @AJPfleger
- 🚨 **BREAKING**: Rename `EigenStepper` dense extension (#3603) by @andiwand
- Update `to_array` (#3600) by @AJPfleger
- Modernise GeometryHierarchyMap (#3594) by @AJPfleger
- Add C++23 `std::ranges::contains` place holder (#3598) by @AJPfleger
- Changed the GeoModelToDetectorVolume to be able to return Acts::Volumes (#3576) by @Berggren-Jonas
- Use `std::ranges::sort` and `reverse` (#3596) by @AJPfleger
- 🚨 **BREAKING**: `VolumeBounds` becomes a scoped enum (#3513) by @paulgessinger
- Make `ViewConfig` usable with designated initializers (#3613) by @paulgessinger
- TrackingGeometry interface cleanup (#3612) by @paulgessinger
- Improved Python bindings for algebra types (#3611) by @paulgessinger
- Modified from_json in AmbiguityConfigJson for easier implementation in Athena (#3628) by @Ragansu
- Visualization3D location and API (#3622) by @paulgessinger
- *(geo)* Portal(Link)+Surface verbosity reduction (#3636) by @paulgessinger
- Reduce abuse of auto in mbf smoother (#3630) by @CarloVarni
- 🚨 **BREAKING**: SourceLink setting only via rvalue reference (#3488) by @paulgessinger
- Remove Sequencer dataflow override (#3625) by @paulgessinger
- 🚨 **BREAKING**: Fuse `Actor` and `Aborter` (#3573) by @andiwand
- 🚨 **BREAKING**: Converge to naming `sourceLink` (#3647) by @AJPfleger
- Remove MPL library (#3642) by @stephenswat
- 🚨 **BREAKING**: Return all track states from Core CKF (#3391) by @andiwand
- Remove redundant `operator!=`, introduce `operator<=>` (#3660) by @AJPfleger
- Remove `inline` from `constexpr` functions for clarity (#3659) by @AJPfleger
- Use `contains` for maps and sets (#3670) by @AJPfleger
- Modernise type traits (#3655) by @AJPfleger
- 🚨 **BREAKING**: Remove mean reduction from `MultiEigenStepperLoop` (#3671) by @andiwand
- Enhance `RootTrackParameterWriter` with residuals and pulls (#3666) by @andiwand
- Removed maxHits condition from ScoreBasedAmbiguitySolver (#3676) by @Ragansu
- Use `std::ranges:find`, `find_if`, `find_if_not` (#3614) by @AJPfleger
- Unify proxy iterator types (#3664) by @stephenswat
- Use `std::ranges::all_of`, `any_of`, `none_of` (#3593) by @AJPfleger
- 🚨 **BREAKING**: Do not use geometry extent during seeding (#3688) by @CarloVarni
- *(geo)* Add portals + surfaces to closeGeometry and visitSurfaces (#3678) by @paulgessinger
- Use std::atan2 instead of atan2f (#3695) by @CarloVarni
- *(gx2f)* Logic for multipleScattering option (no effect yet) (#3551) by @AJPfleger
- *(gx2f)* Remove outdated navigation abort conditions (#3552) by @AJPfleger
- Add C++20 track parameter, navigator, and stepper concepts (#3492) by @stephenswat
- Some refactorings around the G4 simulation (#3532) by @benjaminhuth
- Remove far limit hack from `Layer::compatibleSurfaces` (#3558) by @andiwand
- *(gx2f)* Early exit for `addToGx2fSums` (#3568) by @AJPfleger
- *(gx2f)* Early exit for the Actor (#3566) by @AJPfleger
- Rework G4 surface mapping to make it more robust (#3562) by @benjaminhuth
- Remove `calculateTrackQuantities` from Core CKF (#3567) by @andiwand
- Remove target volume estimation from `Navigator` (#3242) by @andiwand
- Remove remaining detection idiom usage (#3547) by @stephenswat
- Rework projector (#3529) by @andiwand
- Remove input source links from fitting algorithm (#3580) by @benjaminhuth
- Remove GX2F start volume checks (#3581) by @andiwand
- Rework projector (#3453) by @andiwand
- Conditional import & refactor in python scripts related to material mapping (#3518) by @benjar
- Remove `calculateTrackQuantities` from Core CKF (#3536) by @andiwand
- *(geo)* Use hidden friend for SourfaceBounds operators (#3543) by @paulgessinger
- Remove uses of `std::enable_if` (#3484) by @stephenswat
- Remove unnecessary `activeBranches.empty()` condition from Core CKF (#3541) by @andiwand
- RootMaterialDecorator as default for the ODD (#3415) by @benjaminhuth
- Rework `particles_selected` handling in Python Examples (#3423) by @andiwand
- Explicit `checkPathLength` and `isValid` intersection check (#3416) by @andiwand
- Single tree for `RootMeasurementWriter` (#3417) by @andiwand
- Remove `lastHierarchySurfaceReached` from `Navigator` (#3237) by @andiwand
- Resolve surfaces on initialization in `Navigator` (#3283) by @andiwand
- Remove `ProtoTrackTruthMatcher` in Examples (#3410) by @andiwand
- Disable copy&move for `TrackStateType` (#3451) by @andiwand
- Use Core CKF extrapolation after inwards extension in Examples (#3195) by @andiwand
- Physmon: enlarge etaRange for GX2F to match KF settings (#3412) by @AJPfleger
- Rework initial `qOverP` sigma in Examples (#3422) by @andiwand
- Split `GainMatrixUpdater` compilation (#3486) by @paulgessinger
- *(geometry)* Surface merging returns ordering (#3468) by @paulgessinger
- Remove dfelibs from dependencies (#3489) by @paulgessinger
- Change the definition of the rotation parameters (#2021) by @XiaocongAi
- Split `KalmanVertexUpdater` by dimension (#3503) by @paulgessinger
- Remove FPE mask #2284 (marked as #2348) (#3510) by @AJPfleger

CONTINUOUS MIGRATION SCOPE

Example: ACTS v36.0.0 (July 2024) → v37.0.0 (October 2024)

https://github.com/acts-project/acts/releases (changelogs)

Bug Fixes

- Allow resetting reference surface in Track EDM (#3586) by @andiwand
- 🚨 **BREAKING**: Make material validity checks and construction explicit (#3494) by @AJPfleger
- Remove pre-C++20 `std::identity` implementation (#3599) by @AJPfleger
- Stitch tracks correctly after second pass in Examples Track Finding (#3597) by @andiwand
- Adding GeomentryId to detray portals (#3606) by @asalzburger
- Remove `using namespace` in Detray plugin header (#3616) by @paulgessinger
- Reject outliers while trimming track states in Core CKF (#3644) by @andiwand
- Reject material states when no measurements are found yet in Core CKF (#3648) by @andiwand
- Added GeoShapeSubtraction converter for the failing conversion of RPCs to SensitiveSurface (#3592) by @Berggren-Jonas
- Kf+gsf: correct hole-tagging for edge case (#3637) by @AJPfleger
- Replace asctime with `strftime` for safer date formatting (#3658) by @AJPfleger
- *(gx2f)* New error `UsedUnreachableMeasurements` (#3653) by @AJPfleger
- Fix Warning messages (#3679) by @CarloVarni
- Correct initial `q/p` covariance term in `TrackParamsEstimationAlgorithm` in Examples (#3665) by @andiwand
- Fit iterator traits for ContainerIndexIterator (#3689) by @CarloVarni
- BinUtility was auto-convertible from Transform3 (#3691) by @paulgessinger
- Setting current surface fix for DetectorNavigator (#3401) by @asalzburger
- Fix and enable testing for RefittingAlgorithm (#3404) by @benjaminhuth
- Fix try all navigators after running with track finding (#3408) by @andiwand
- Add default value to ReadOnly in ScoreBasedAmbiguityResolution (#3418) by @Ragans
- `Vertex::setPosition(Vector3)` should only set position (#3421) by @andiwand
- Comparison error in DirectNavigator (#3424) by @benjaminhuth
- `VectorTrackContainer::removeTrack_impl` (#3427) by @andiwand
- *(sonar)* Move/forward, avoid slicing, noexcept destructors (#3396) by @paulgessinger
- Improve CKF error handling and fix path limit abortion (#3436) by @andiwand
- Correct handling of outliers and holes for track statistics (#3438) by @andiwand
- Handle holes after measurement selection in Core CKF (#3413) by @andiwand
- Fix proto layer range for straw surfaces (#3443) by @XiaocongAi
- Next round of RefittingAlgorithm fixes and hash checks (#3430) by @benjaminhuth
- Remove residual mentions of C++17 (#3455) by @stephenswat
- Select binning dimension in cuboid volume builder (#3463) by @AJPfleger
- *(gx2f)* Constrain update to initial volume (#3411) by @AJPfleger

Performance

- Use `SympyStepper` over `EigenStepper` in Examples (#3459) by @andiwand
- Optimize SourceLink creation, track state assignment (#3466) by @paulgessinger
- Drop `stateBuffer` from Core CKF (#3458) by @andiwand
- Improve Hough Transform performance (#3461) by @dimitra97
- Use sympy generated transport jacobians for sympy covariance transport (#3650) by @andiwand

…AND MUCH MORE !!!

Build, Testing, Documentation,
Miscellaneous changes (moving to C++ 23…)

How to run:

toolbox enter a9-nica-dev

module add mpddev ACTS/v36.0.0-1

build mpdroot's dev branch

runReco.C with ETpcTracking::ACTS

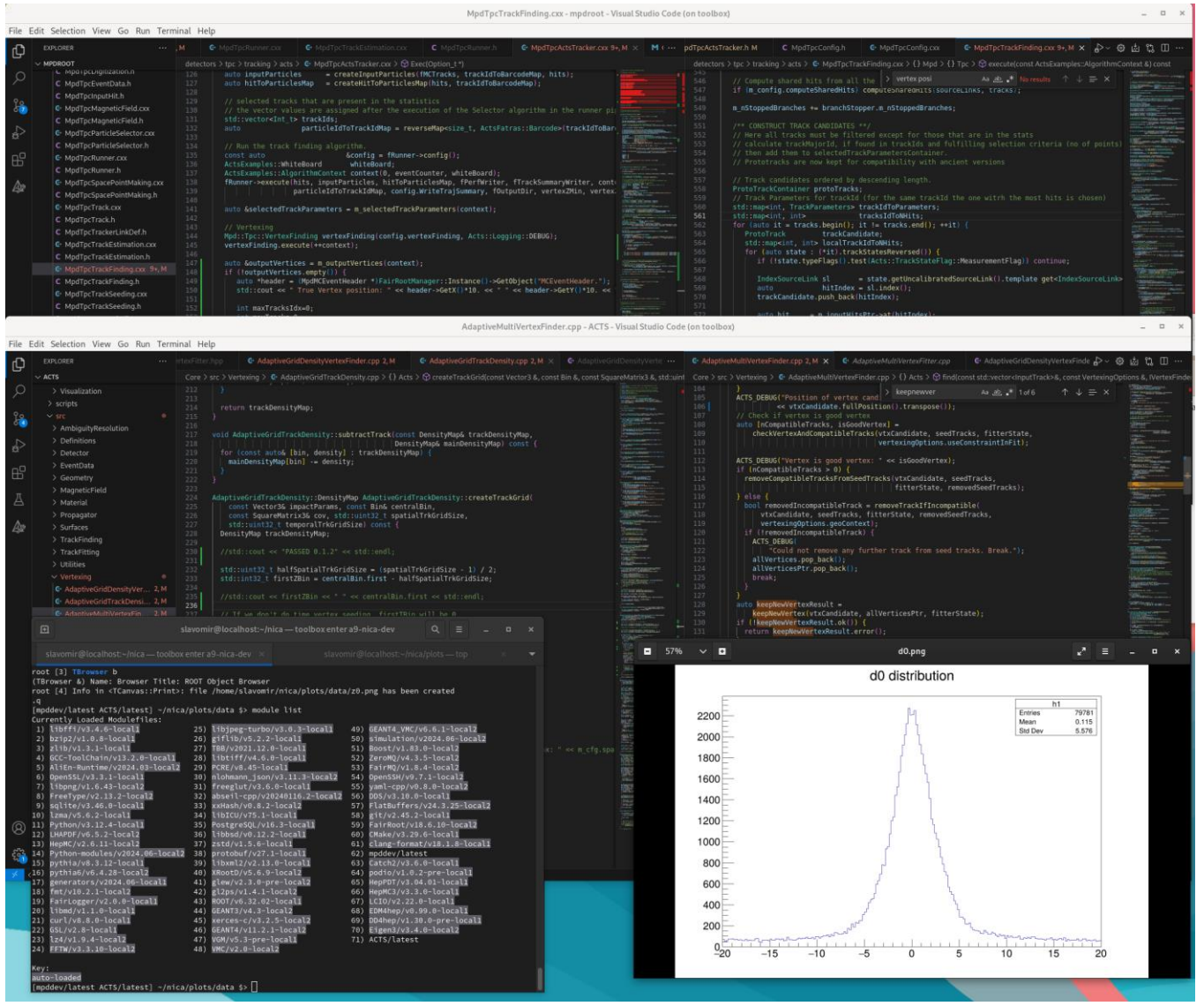
MIGRATION

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
- Developing features needed for MPD outside of MPDRoot

Effective development otherwise impossible

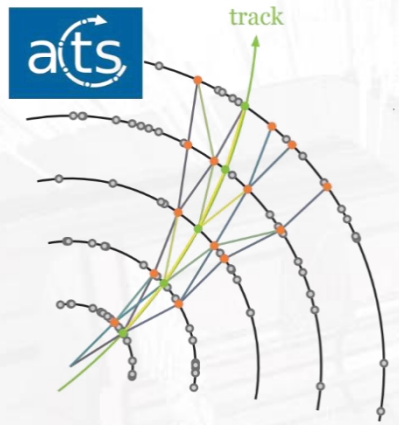
- Lack of documentation
- Overall complexity

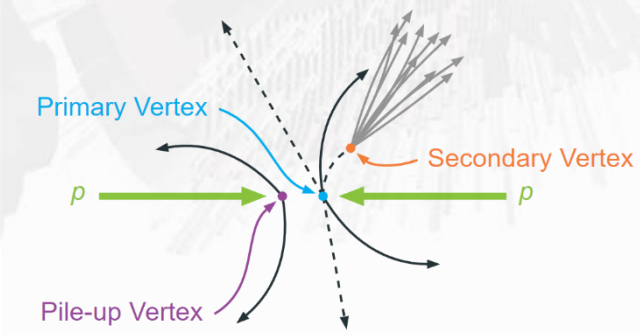


ACTS VERTEXING IN MPDROOT

TRACKING PIPELINE

- Virtual geometry
- Input Hits
- Projection
- Seeding
- Input KF parameters
- Track finding
- Selector
- Vertexing (primary)
- TOF Matching





VERTEXING

- Seed finding
- Vertex finding
- Vertex fitting

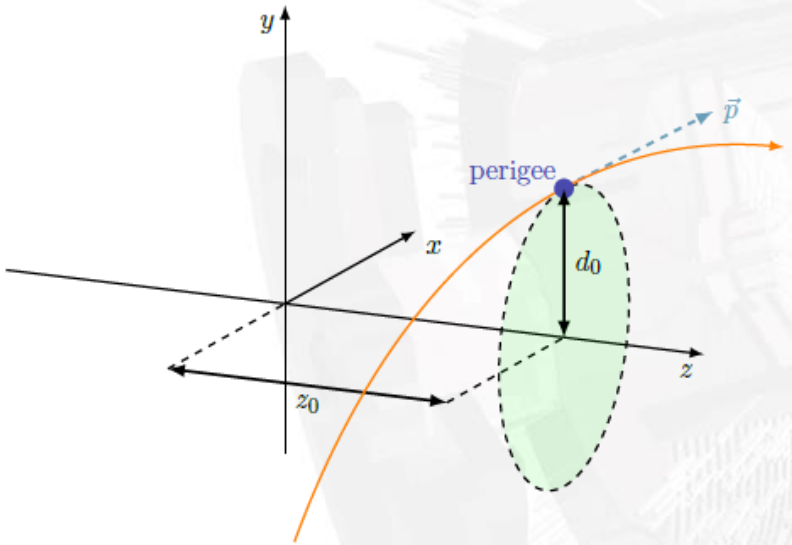
Algorithms

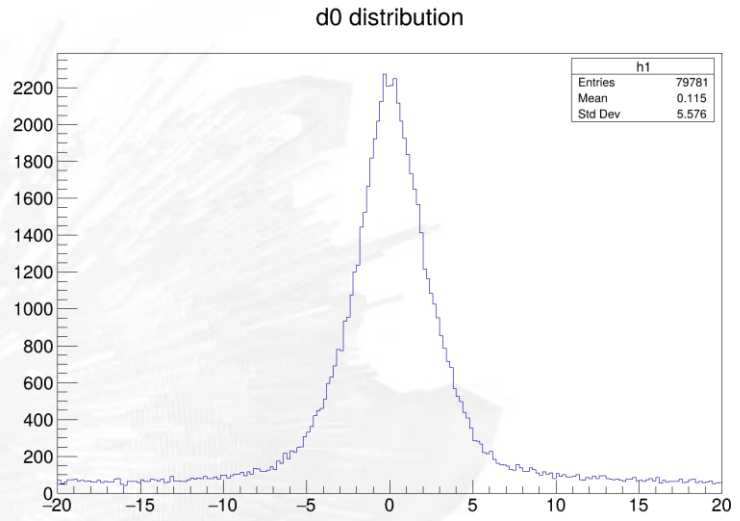
IVF: fitting-after-finding

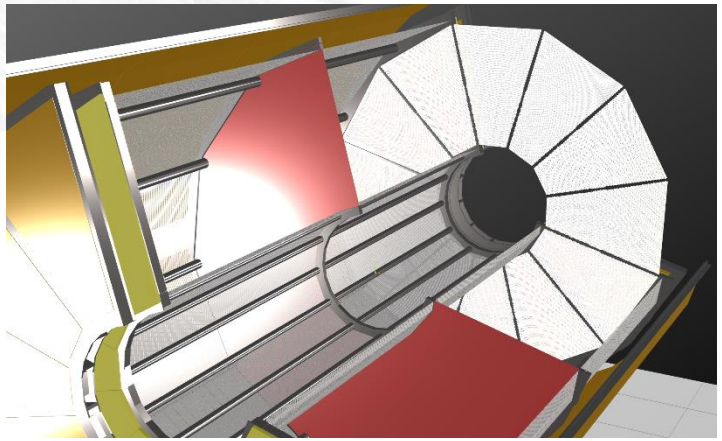
AMVF: finding-through-fitting

TRACK SELECTION

PERIGEE TRACK PARAMETRIZATION





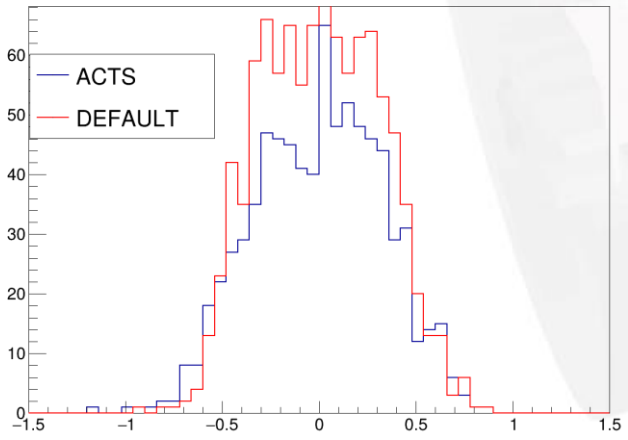


PRELIMINARY RESULTS

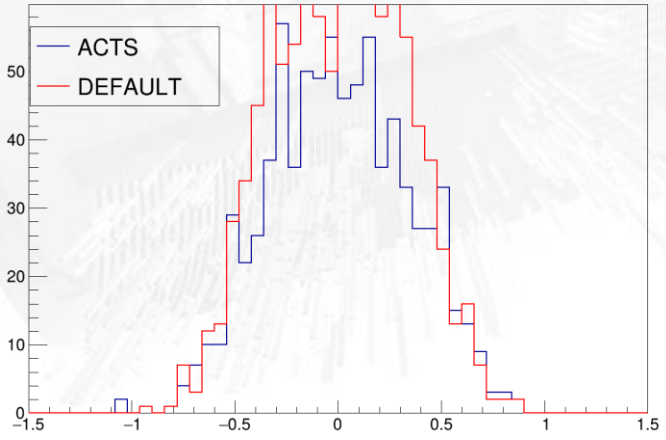
AMVF vs DEFAULT PRIMARY VERTEX FINDER

1000 events, BOX generator

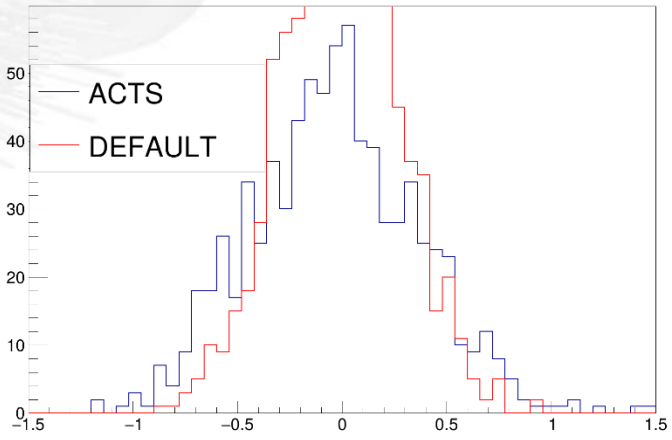
- |d_0| < 2mm, apart from that no tuning
- fine-tuning to be done by somebody junior (or TBD later)
- In some events seed not assigned (solvable)



$X\text{-}X_{true}$



$Y\text{-}Y_{true}$

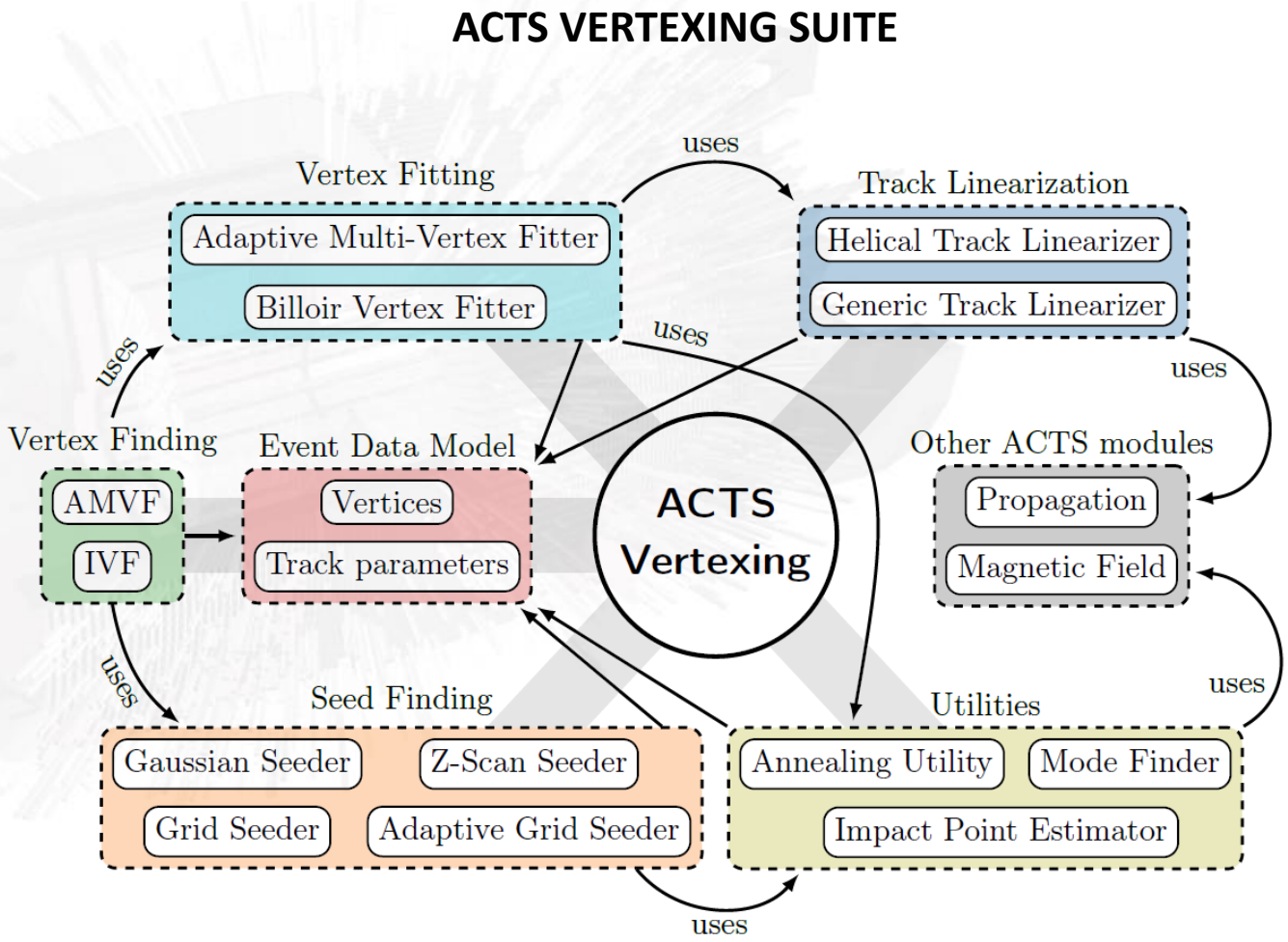


$Z\text{-}Z_{true}$

VERTEXING SUITE

- a lot of components
- too many parameters to tune, which can be time consuming
- documentation lacking

Way out: use virtual machine with full alibuild



FUTURE

ACTS

- TOF matching (finalize integration into global reco)
- Optimize virtual geometry
- Vertex Finder tuneup
- Optimization of Acts tracker configuration parameters (speed, efficiency)
- Refactoring, phase out obsolete API (prototracks, hit-particle matching…)
- Remove outdated statistics utils, move to native ACTS utilities
- Disconnected tracks

SOFTWARE DEVELOPMENT

- up to date with latest packages (Acts, ROOT, …)
- regular release schedule
- automated tests
- cleanup
- refactoring

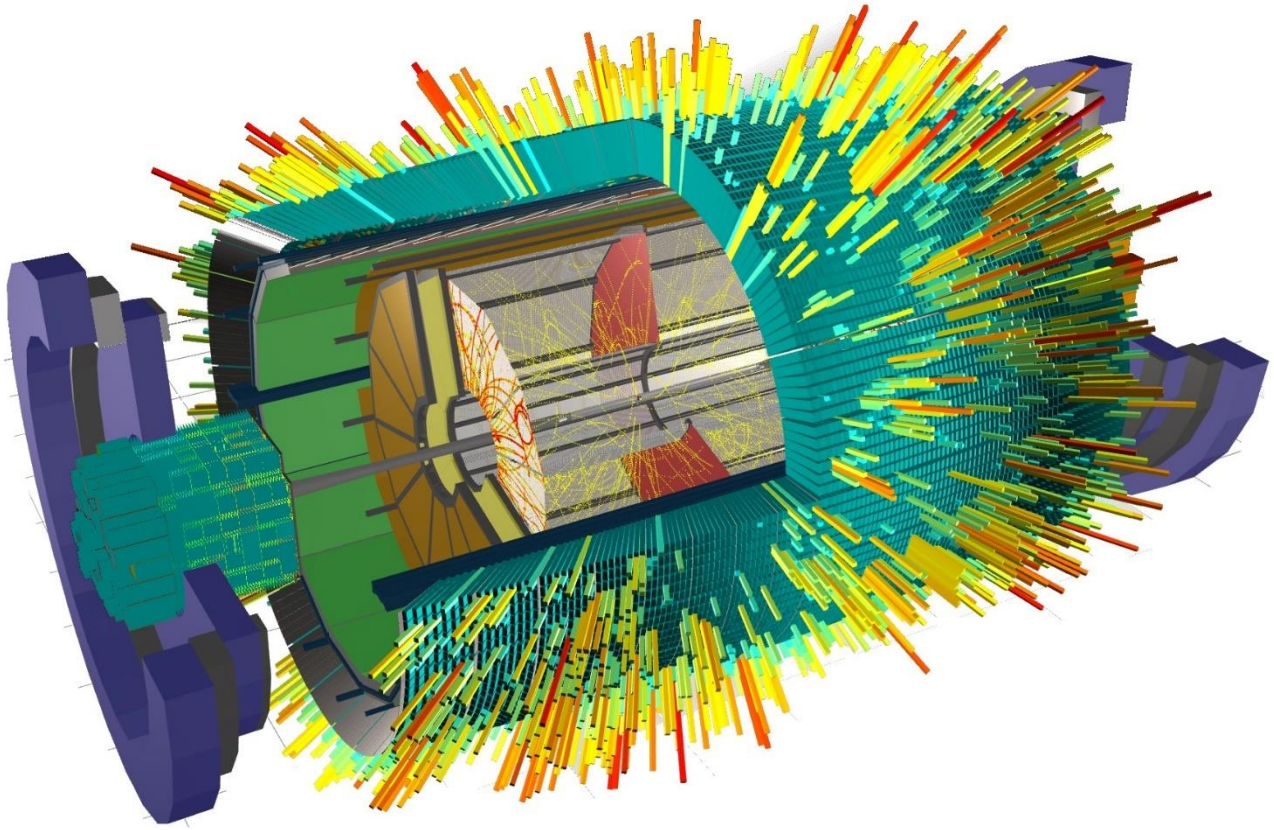
CLUSTERING

- Improve accuracy level of Fast algorithm (edge cases, benchmarking)
- Integration of Wavelet algorithm

ESSENTIAL CRITERION – real experiment reusability (QA toolkit)

Thank You !

Q & A



MPD Software Development & Computing Team

Rogachevsky O.	Coordinator
Krylov V., Krylov A.	Online MPD Event Display
Moshkin A., Pelevanyuk I.	Mass Production
Bychkov A.	Detector Simulation
Kuzmin V.	Detector Alignment
Podgainy D., Zuev M.	Supercomputing
Alexandrov E., Alexandrov I.	Databases
Balashov N.	Gitlab Support
Belyakov D.	Network Infrastructure
Belecky P., Kamkin A., Hnatic S.	Acts Tracker
Busa J.	Build System
Hnatic S.	Architecture