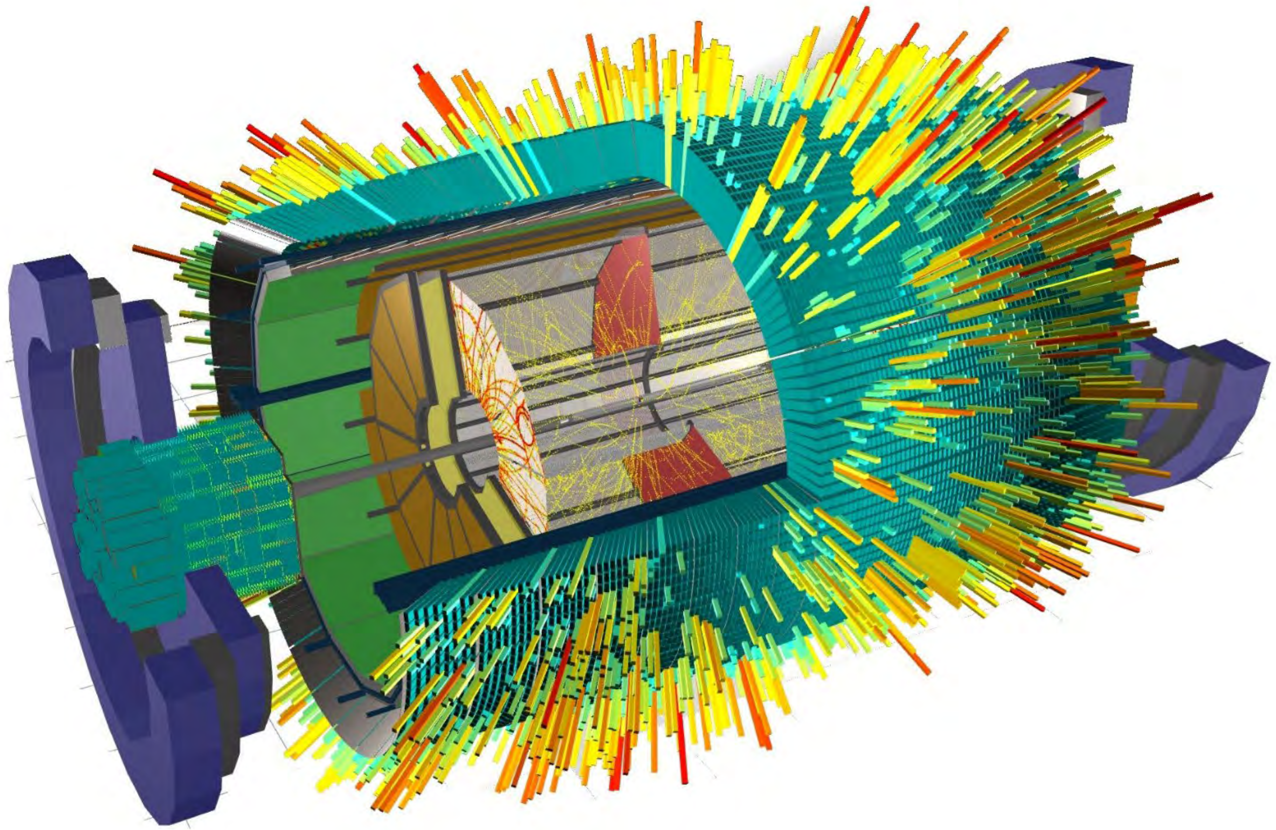
Software Development & Computing for the MPD Experiment

HNATIC Slavomir

on behalf of the

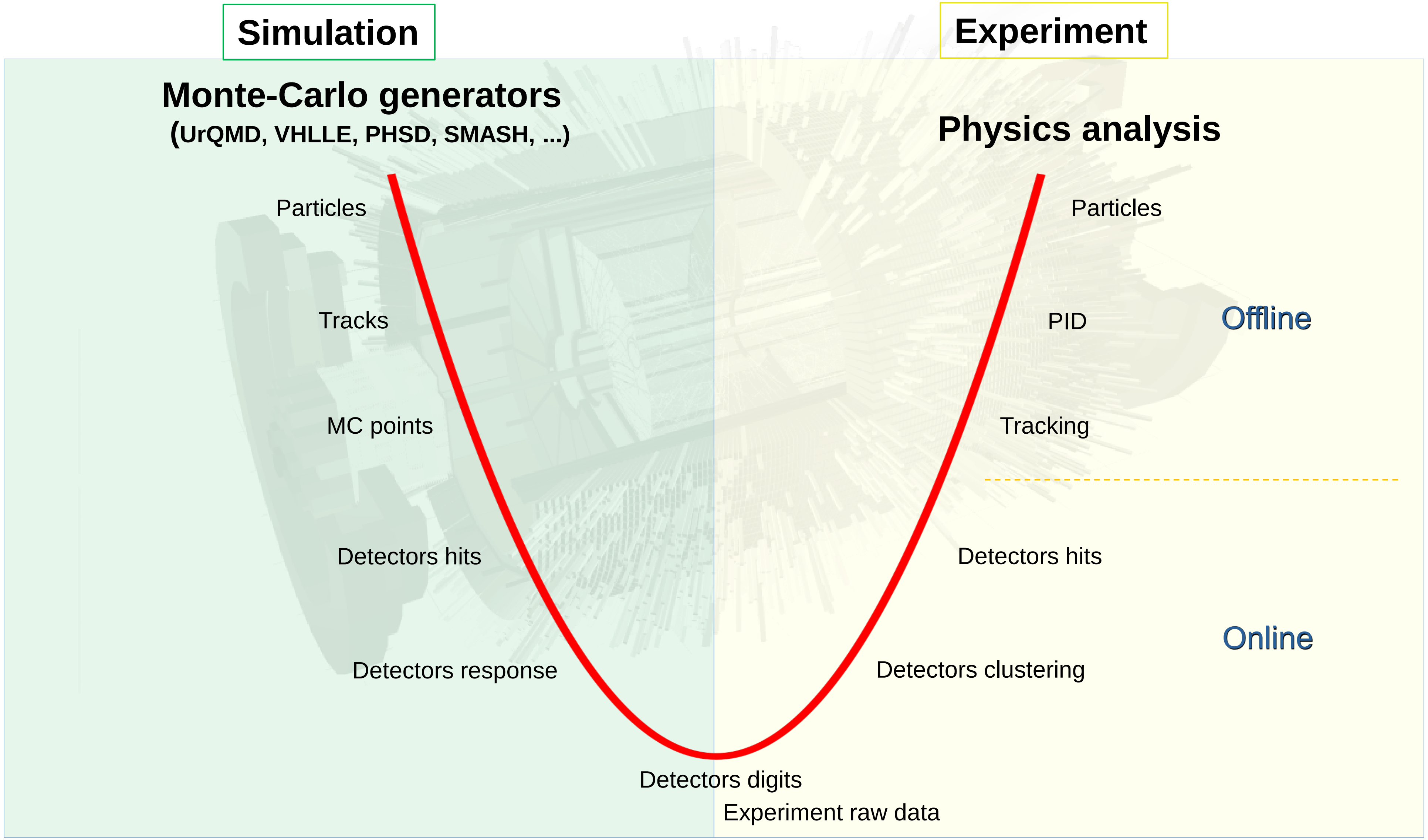
MPD Software Development & Computing Team



OUTLINE

- Big Picture
- Online Software
- Detector Calibration
- Data Processing
- Offline Software
- Computing
- 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

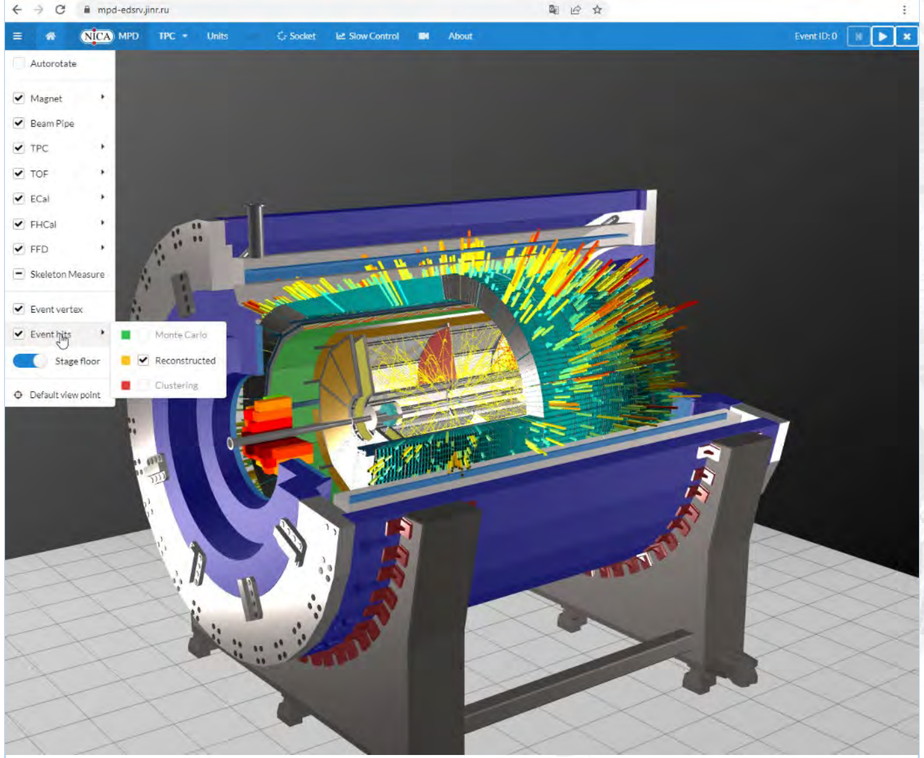
ONLINE EVENT DISPLAY
- experiment visualization
- QA

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

DATA
- storage & retrieval
- adjustnment
- clustering

MPD EXPERIMENT VISUALIZATION

MPD EVENT DISPLAY
- https://mpd-edsrv.jinr.ru/
- powerful feature-rich professional grade software for the visualization of MPD experiment



- superfast webGL 3D-graphics technology at its core
- compatible with any web browser

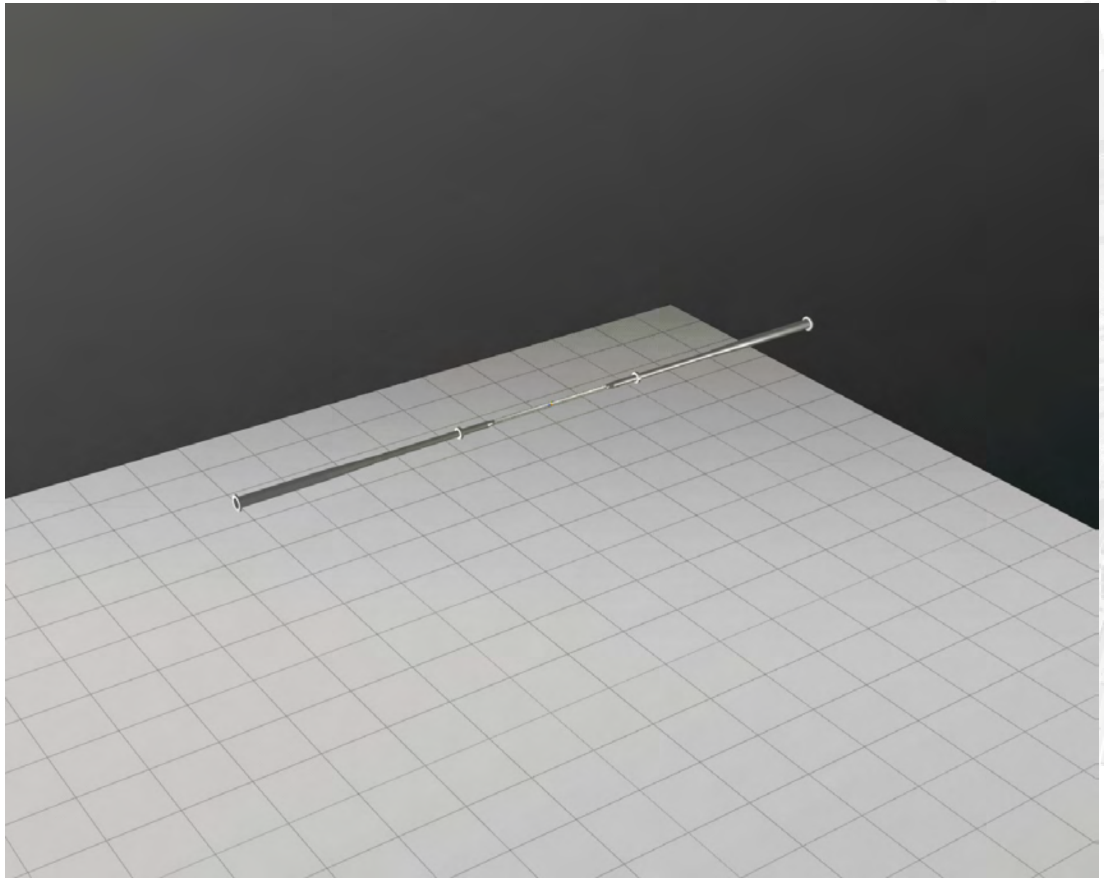
More information:
A. Krylov, Modern Web Technologies in Event Display Creation for High-Energy Physics

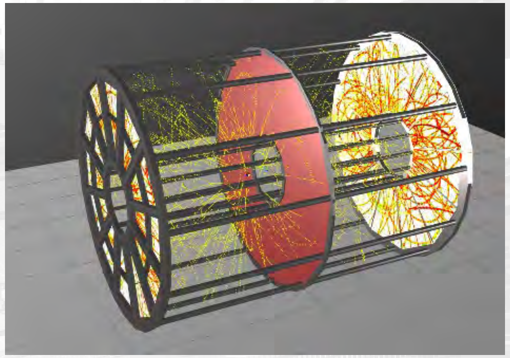
FEATURES

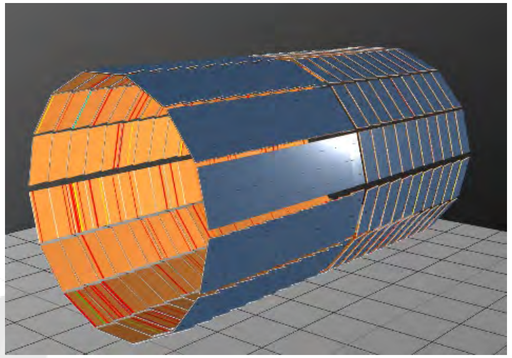
- modular interactive "on-click" geometry
- target online visualization capability 1 event per sec (once experiment running),
  currently played from root files
- fast TPC hit reconstruction
- MC tracks visualization
- reconstructed hits/tracks (from DST file)

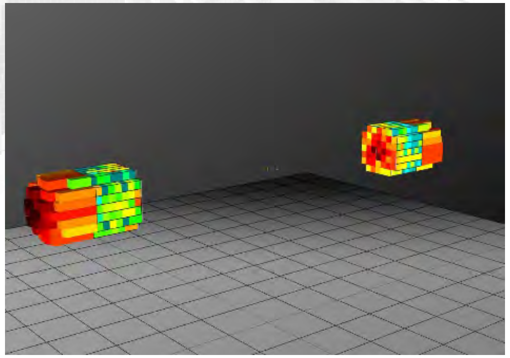
ALICE experiment control room

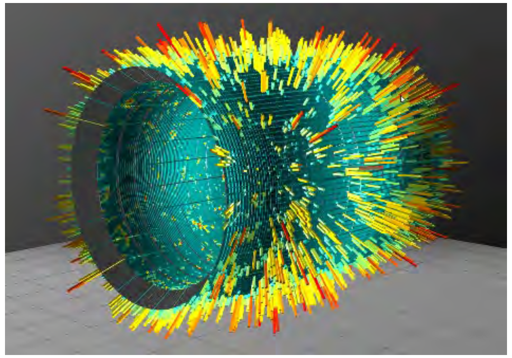
MPD EXPERIMENT VISUALIZATION



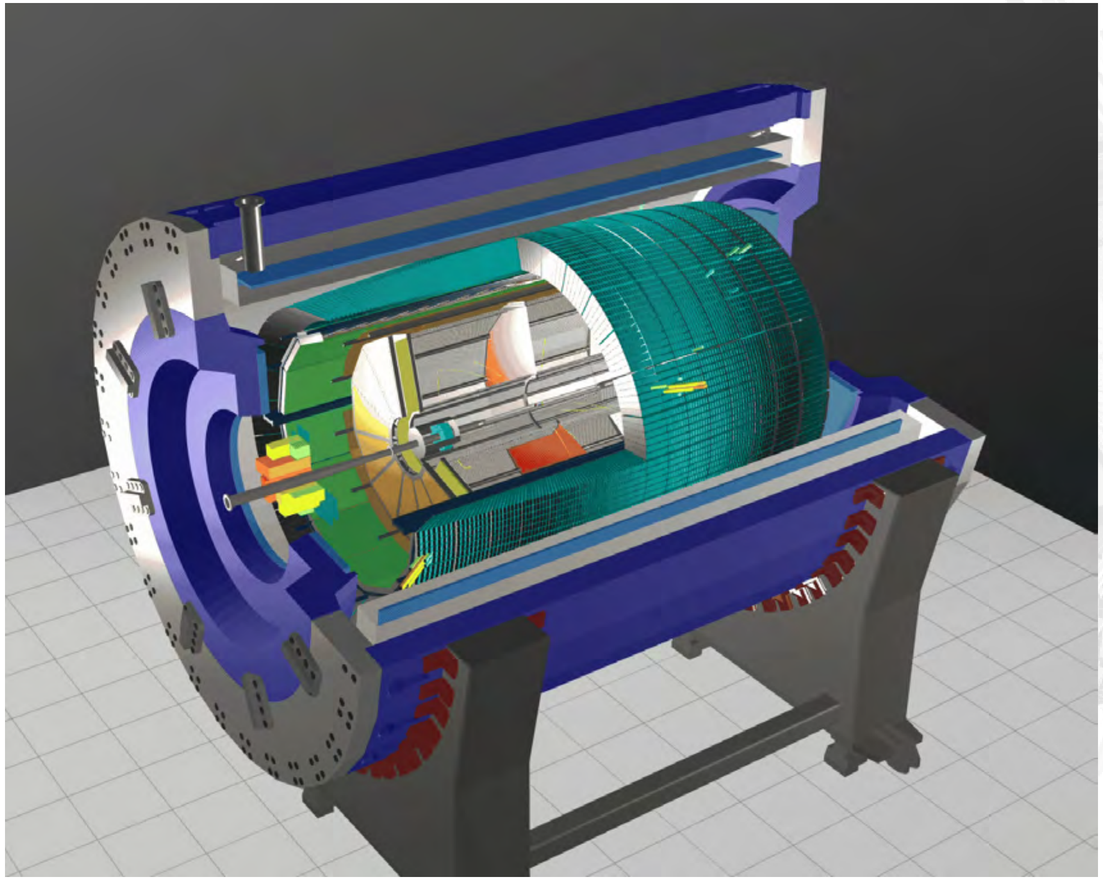








MPD EXPERIMENT VISUALIZATION



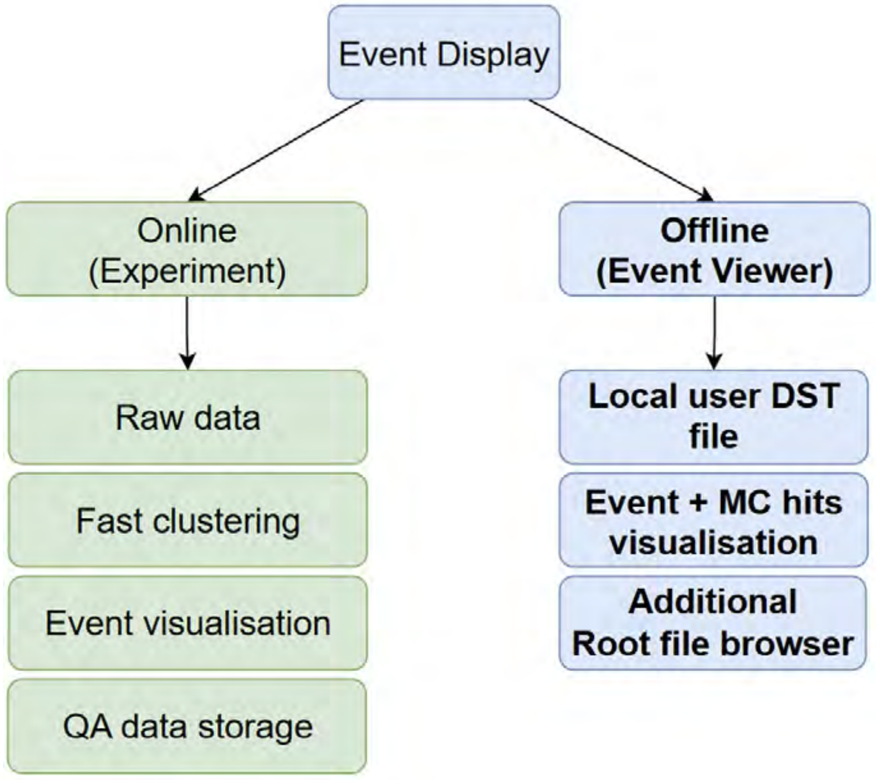
Online QA Histograms

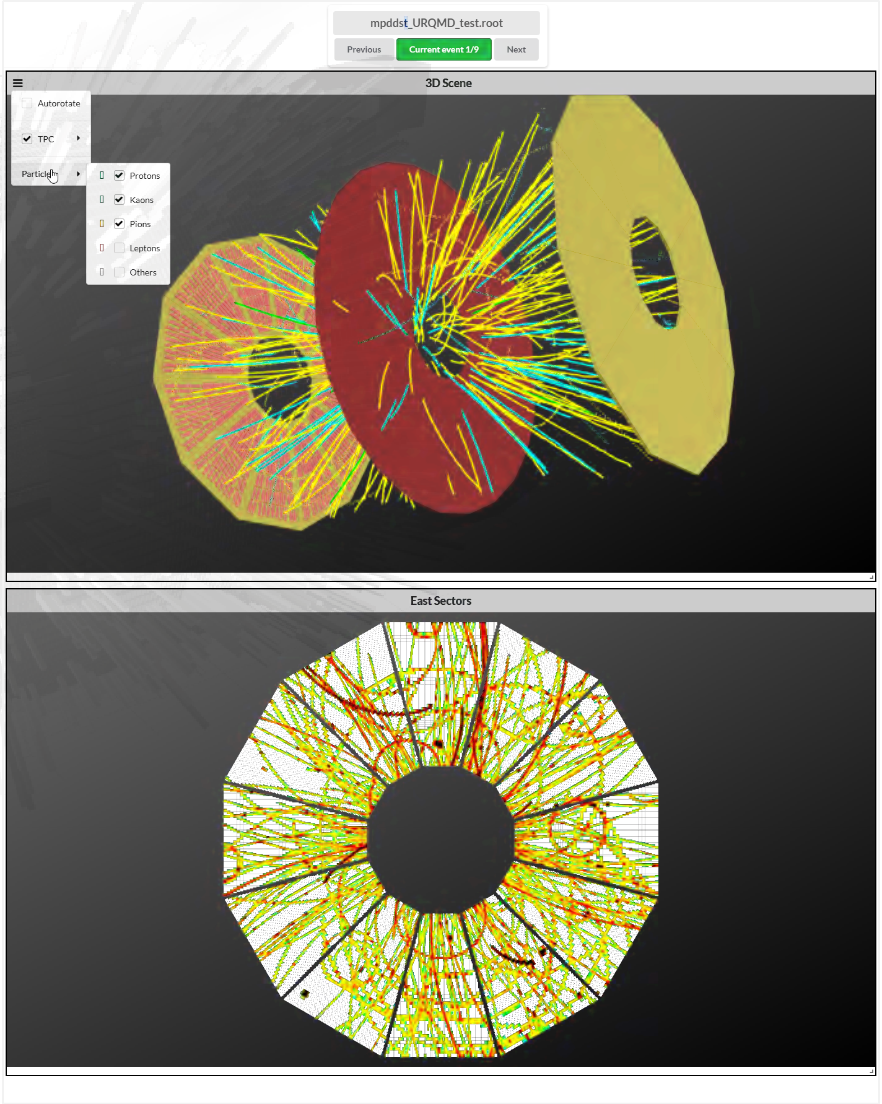
- Inner pads ADC distribution per sector – 24
- Outer pads ADC distribution per sector – 24
- Inner pads ADC distribution per timebucket – 24 (per sector)
- Outer pads ADC distribution per timebucket – 24 (per sector)
- Inner pads ADC distribution for current event – 24 (per sector)
- Outer pads ADC distribution for current event – 24 (per sector)
- General clusters information – 6

Total number of TPC QA histograms – 150

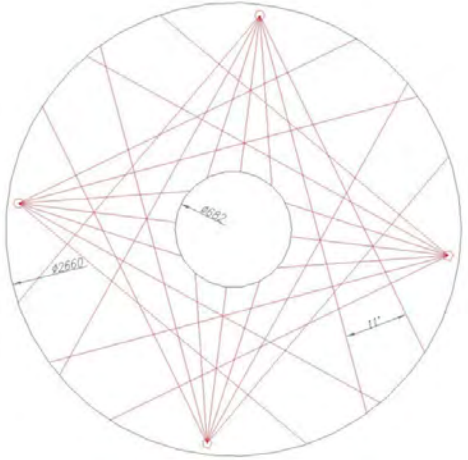
kubernetes

MPD EXPERIMENT VISUALIZATION



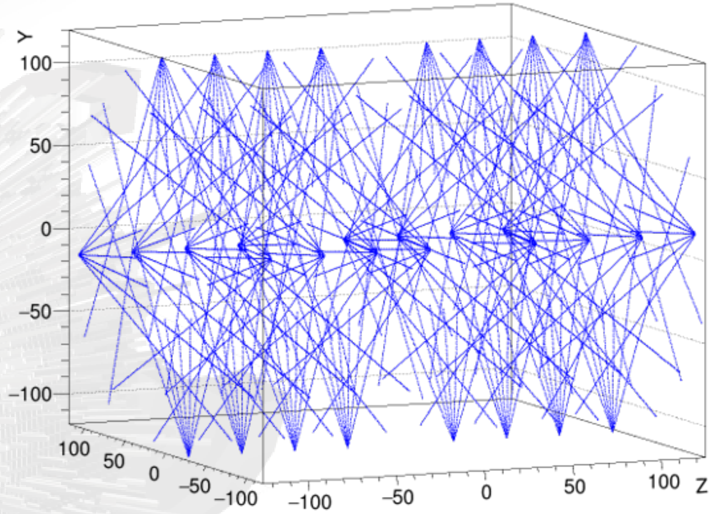


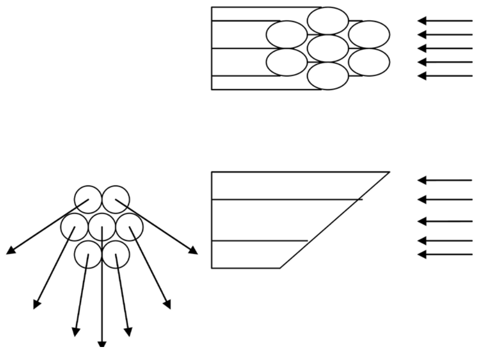
TPC LASER CALIBRATION

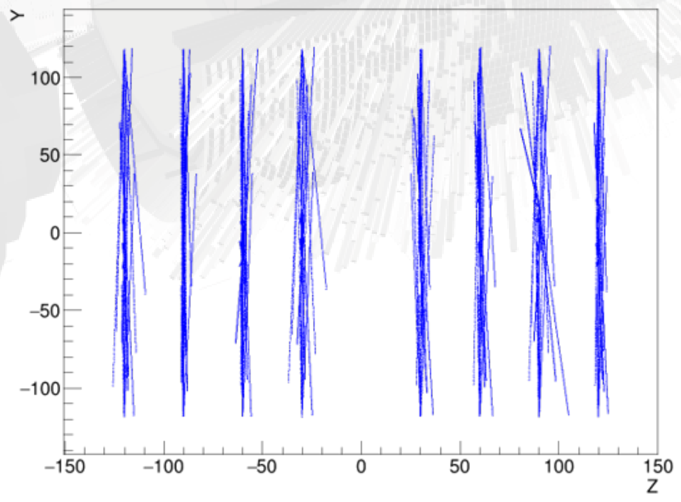


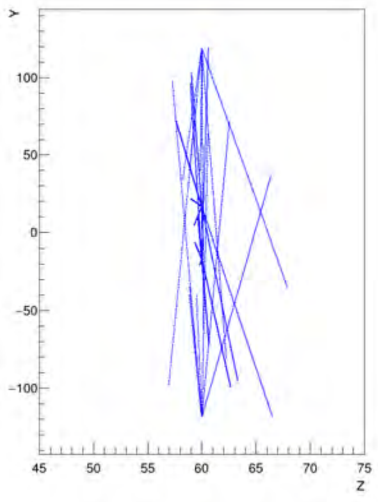
UV laser system to provide “tracks” with known position to get drift velocity

- Two pulsed lasers
- ~1mm diameter
- 112 “tracks” in each half of the TPC
- 4 planes of laser beams



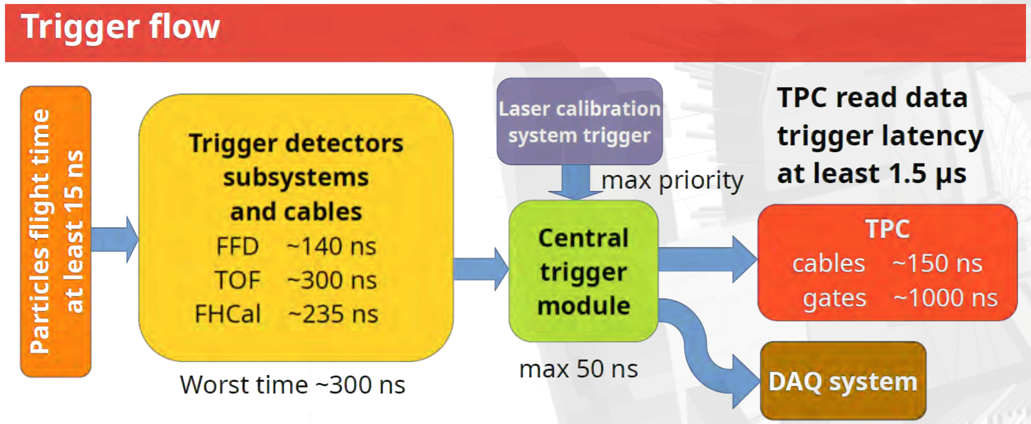






A.Bychkov

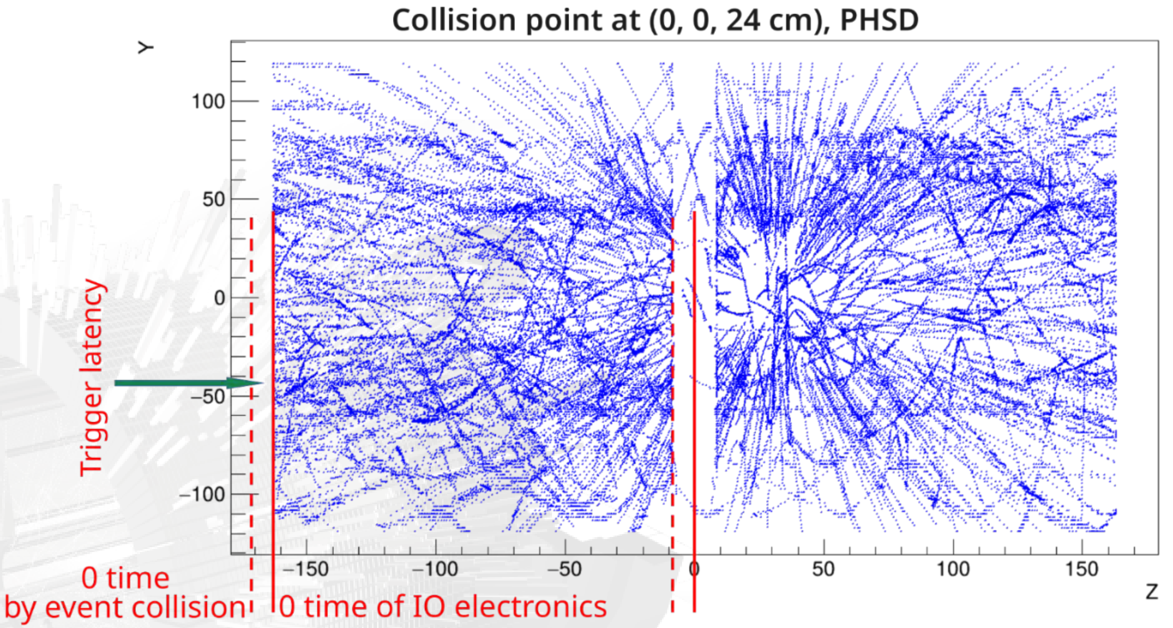
TRIGGER LATENCY

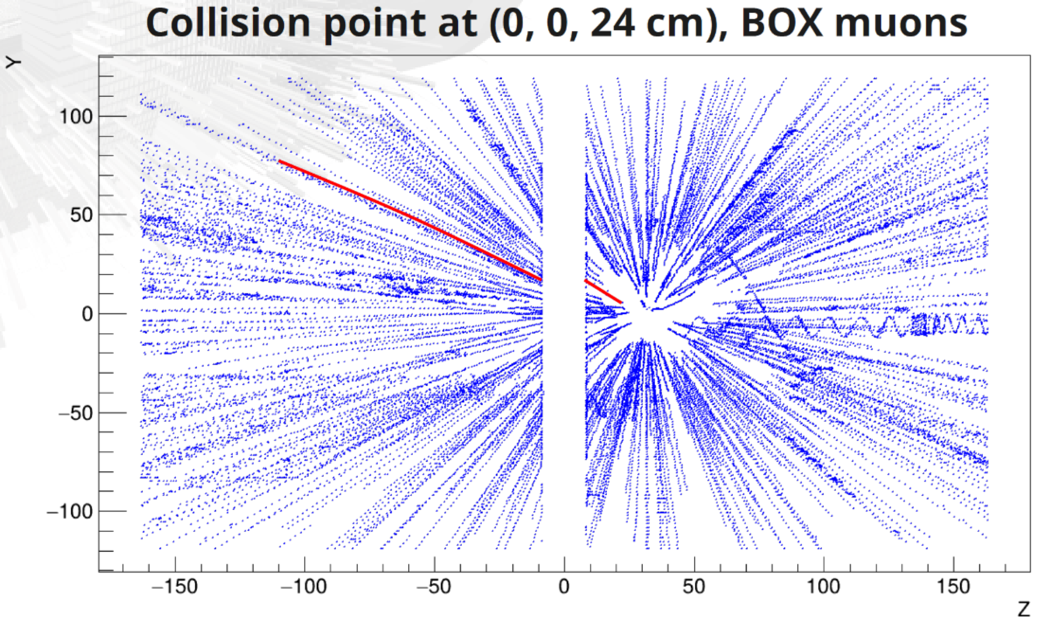


“Implementation of Task for Calibration of MPD TPC Electron Drift Velocity”

Bychkov, A.V., Rogachevsky, O.V., Hnatic, S.

PEPAN Letters, 2024





A.Bychkov

ELECTRONICS RESPONSE CALIBRATION

Read-out channel parameters

100 ns – time bucket, 310 time buckets

>95000 read-out channels in total

SAMPA impulse shape function

$$f(x) = \left(\frac{x-t}{\tau}\right)^N e^{-N\left(\frac{x-t}{\tau}\right)} + Bl$$

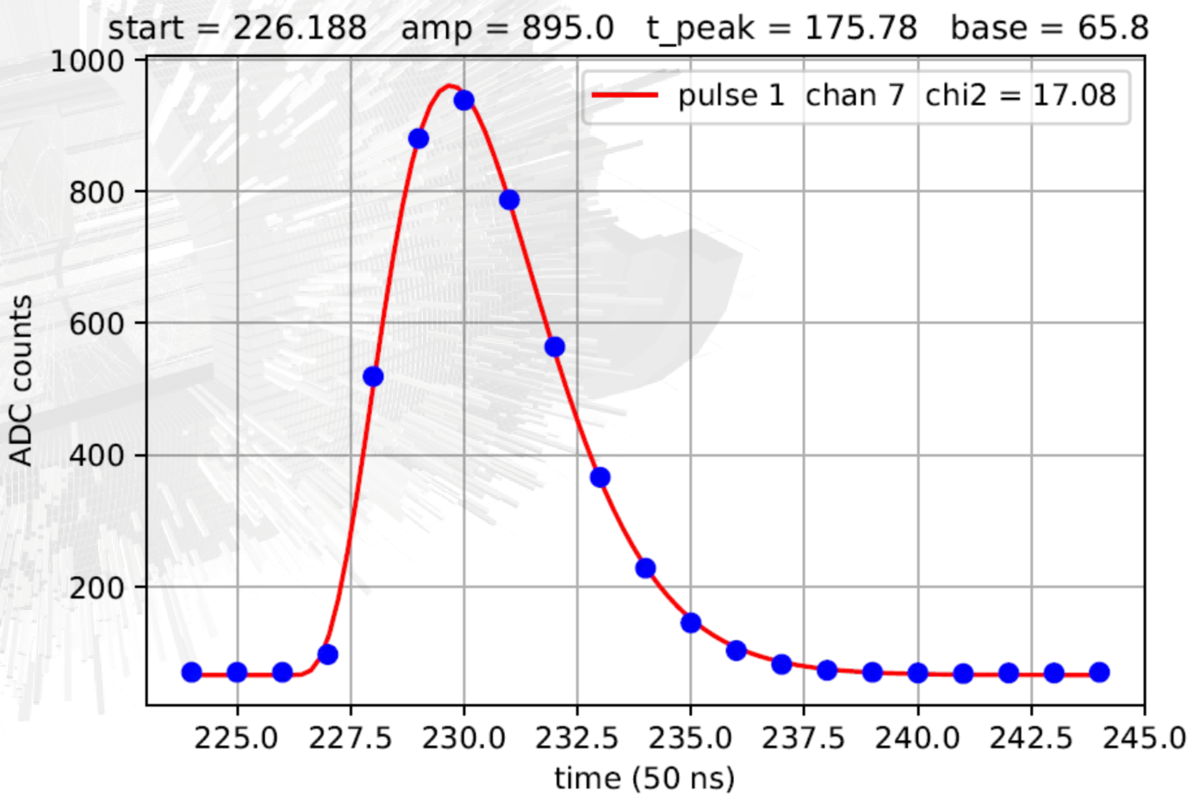
N = 4 — shaping order

τ = 160 — peaking time (ns)

Bl = 0 — baseline

t — start time

Ae^{-N} = 20 (30) — amplitude (fC per mV)



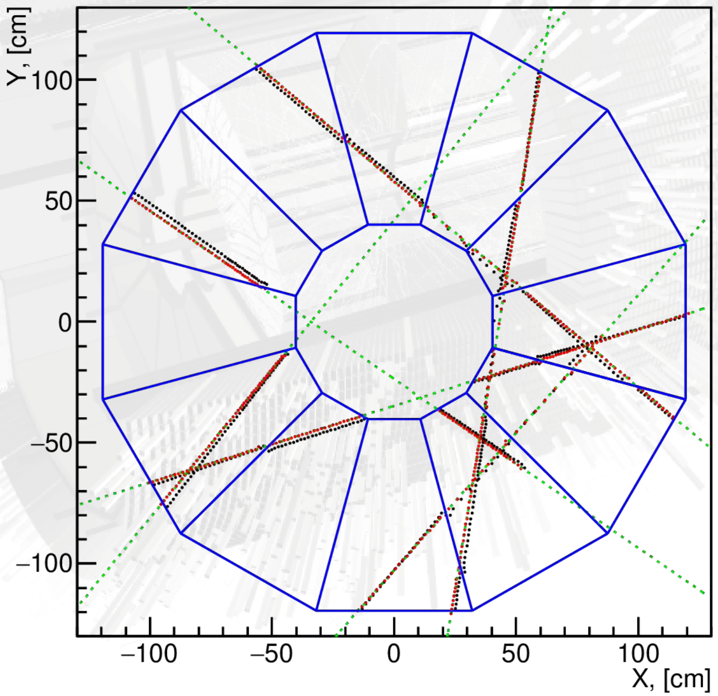
- realistic SAMPA digitizer was developed

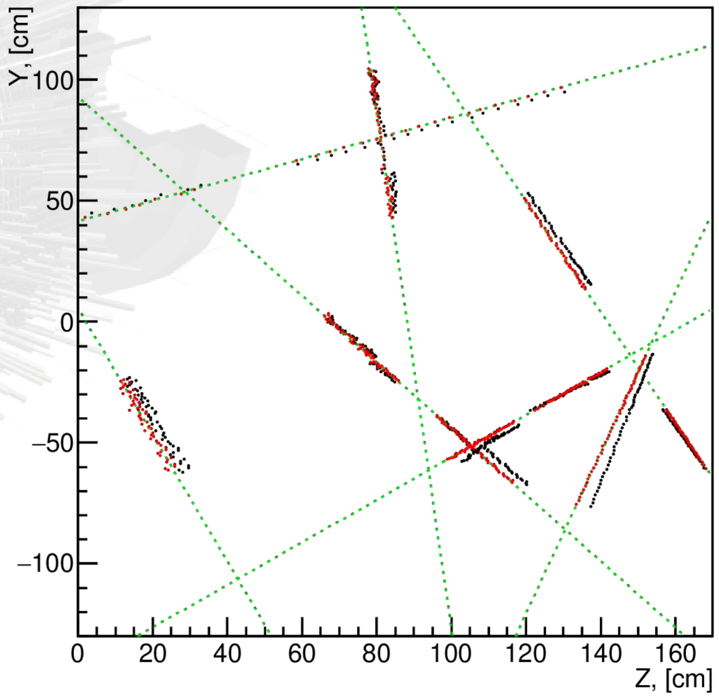
A.Bychkov

TPC SECTORS ALIGNMENT

Green points – simulated muon tracks
Black points – misaligned hits
Red points – aligned hits

- misaligned detector giving misaligned data
- mathematical model with 144 input parameters
- determine transformation for data alignment

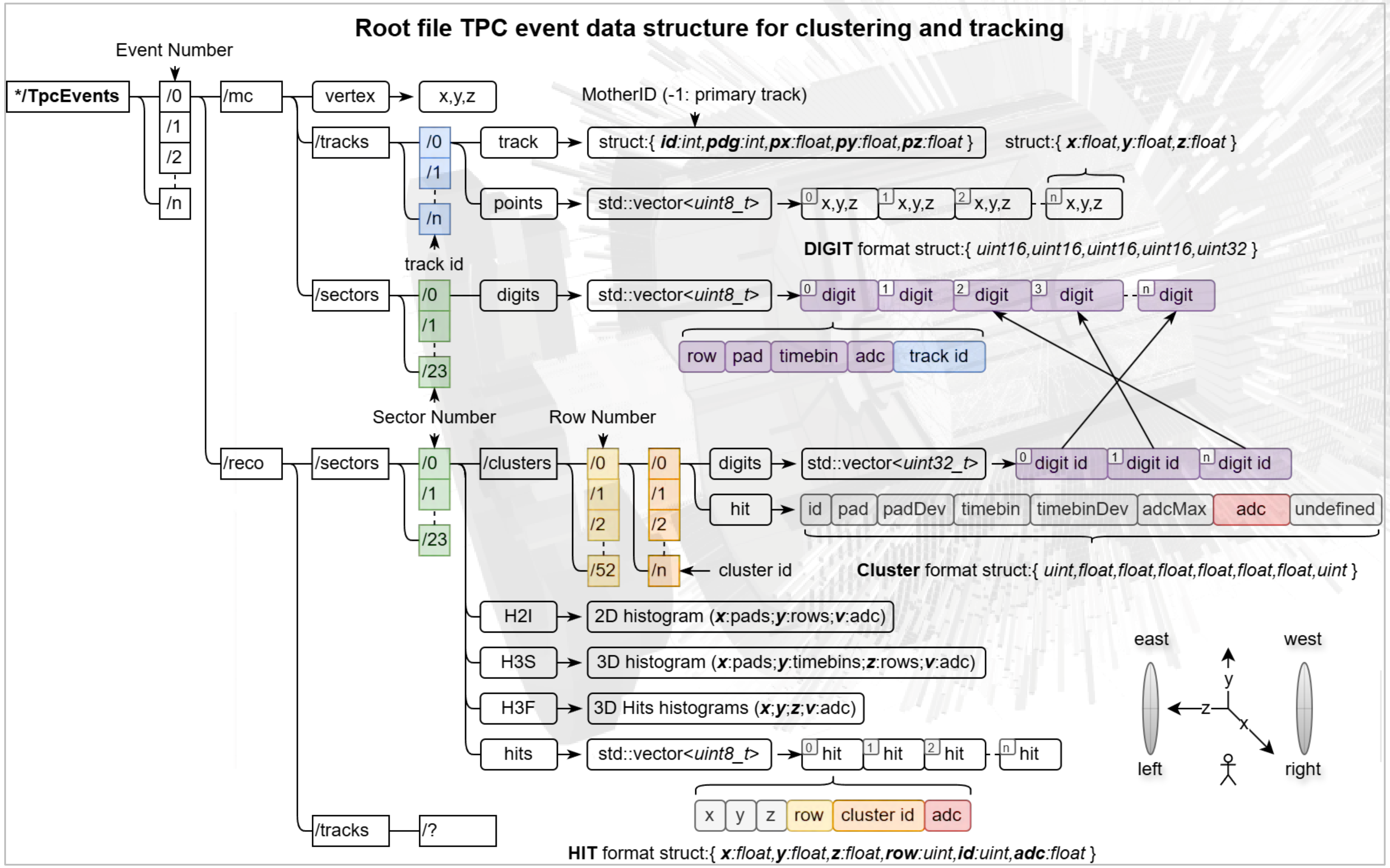




"Influence of Misalignment on Track Reconstruction in the Time Projection Chamber of the MultiPurpose Detector"
V.A.Kuzmin

Moscow University Physics Bulletin, Vol. 80, No 3., 2025

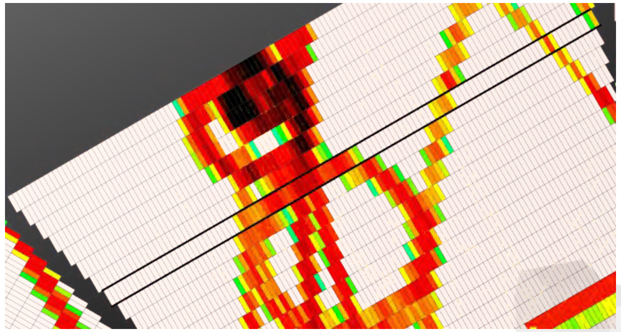
INPUT DATA STRUCTURE



Experiment

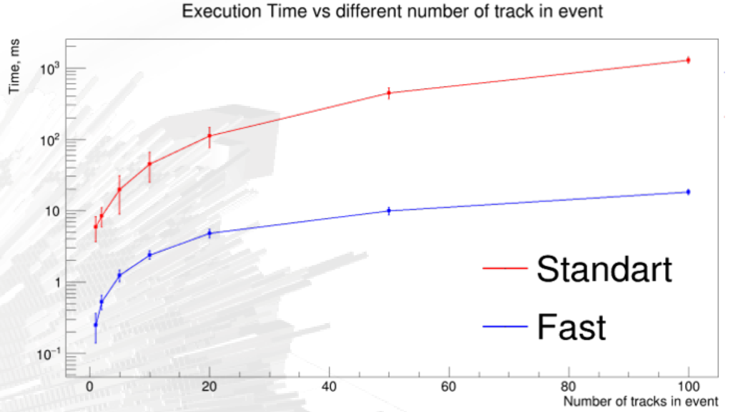
- SAMPA data
- detector calibration parameters
- noise information
- no mc branch

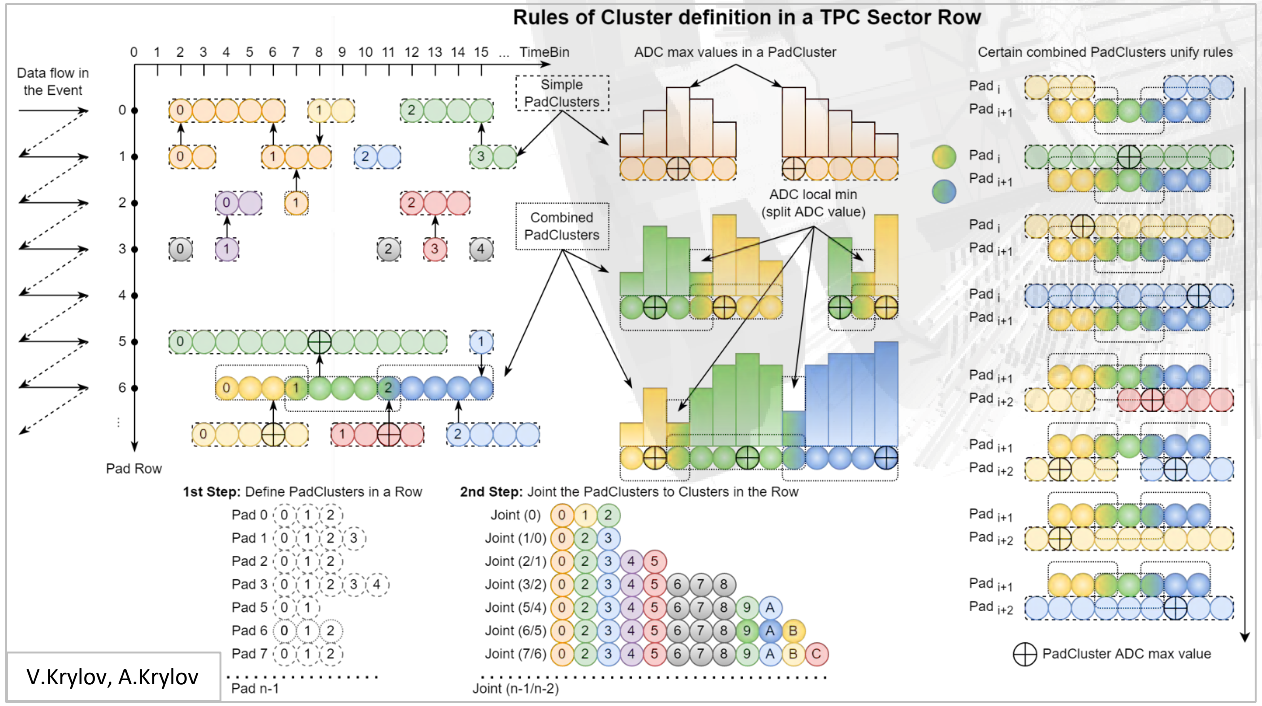
CLUSTERING & HIT EXTRACTION

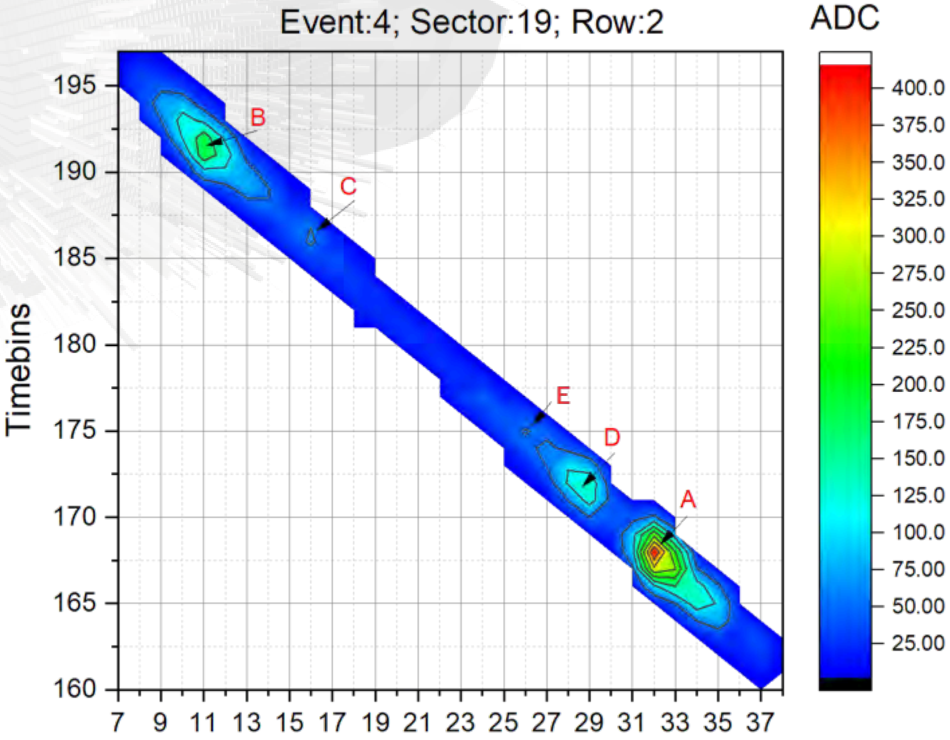


FAST CLUSTERING

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





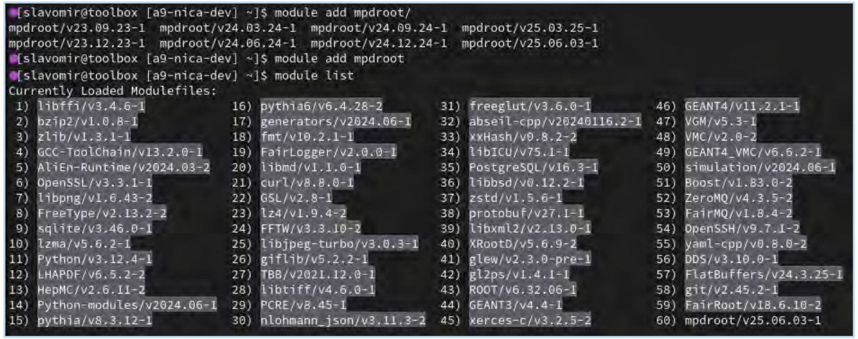


MPDROOT: USER PERSPECTIVE

INSTALLATION
https://mpdroot.jinr.ru/running-mpdroot-on-local-machine-using-cvmfs/

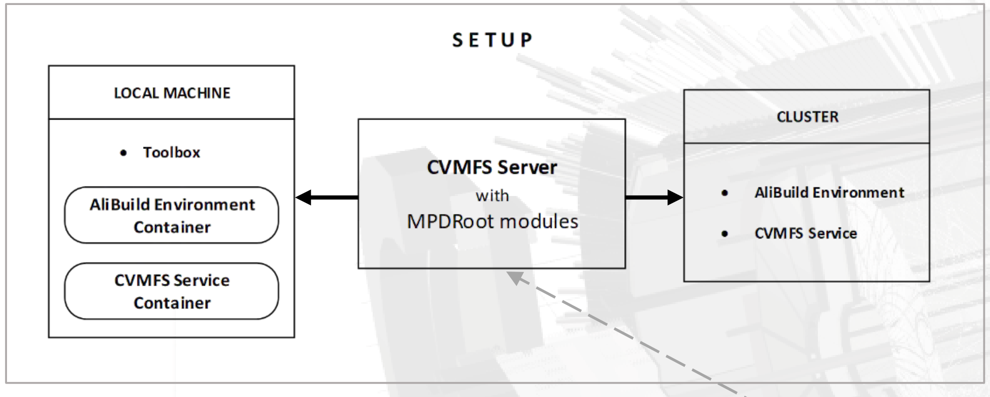
ENVIRONMENT & DEPENDENCIES
- the environment & dependency tree for the same mpdroot or mpddev versions are **identical**
- no compatibility issues by definition

RELEASES
- release schedule: every 3 months
- “module add mpdroot” loads latest mpdroot/v25.06.03
- old releases can be loaded using specifier
- every release is coupled to its own dependency tree



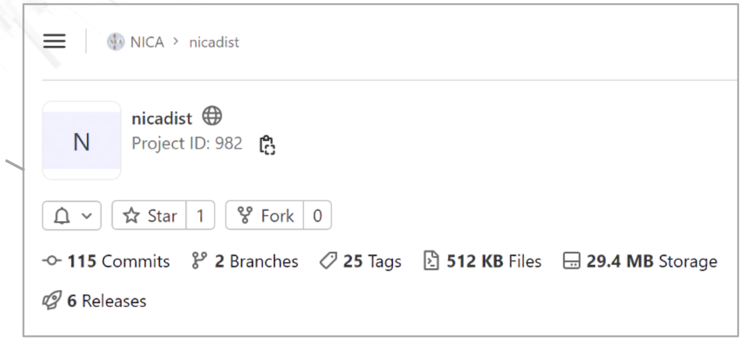
USER SUPPORT
- service desk at http://mpdroot.jinr.ru/q-a/

BUILD & DEPLOYMENT SYSTEM



NICADIST project

- build system decoupled
- modular build
- builds packages from sources & keeps track of their dependencies
- sophisticated solution of "dependency hell"
- inspired by ALICE project



- Quick, user-friendly installation
- Unified environment for users and developers, guaranteed compatibility
- No build & configuration for users
- Less support required
- Easy updates, less maintenance

"Unified Software Development and Analysis Environment for MPD Experiment at NICA Collider"
Busa J. Jr., Hnatic S., Korenkov V., Rogachevsky O., Vala M., Vrlakova J.

Modern Information Technologies and IT-education , 2022

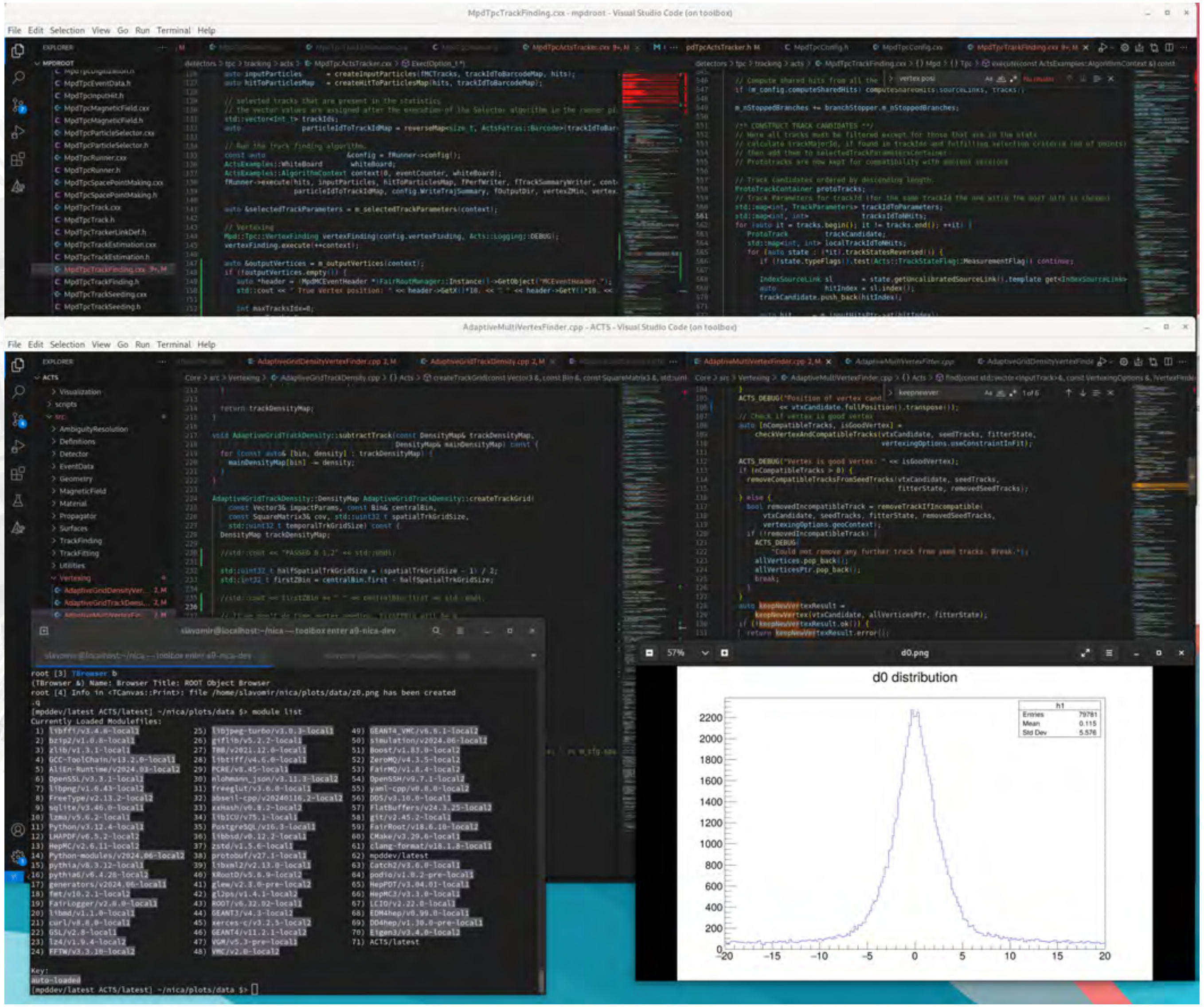
MIGRATION, CUSTOM PACKAGES

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

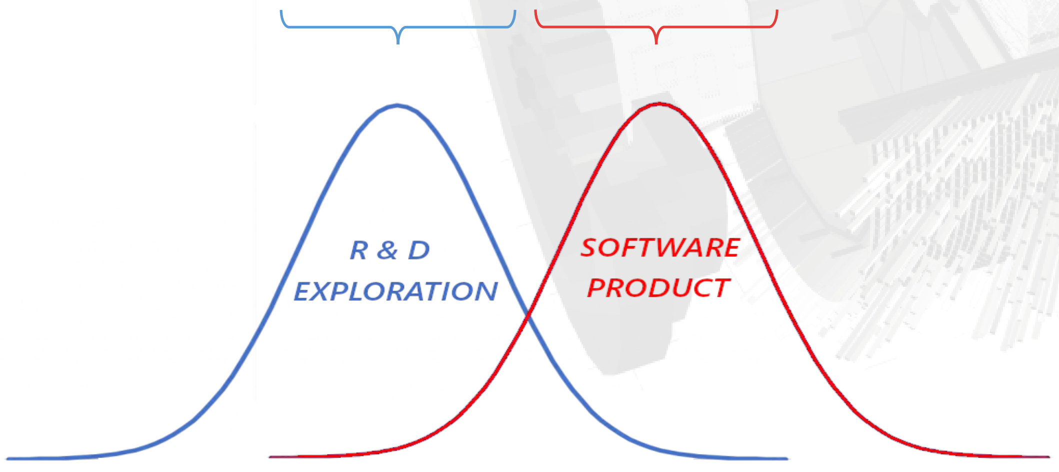


SD BEST PRACTICES

"…the profession in which a knowledge of the mathematical and natural sciences gained by study, experience, and practice is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind."

-- Accreditation Board of Engineering & Technology (www.abet.org)

Technology Development =
Scientific Theory + Engineering Practice + Economy



ACTIVITIES FOCUS

SEPARATION OF CONCERNS

- thinking of software entity attributes in isolation, while keeping in mind, they're part of the whole

E.Dijkstra "On the role of scientific thought" (1974)

CORE INFLUENCES

- size / scaling
- structural complexity
- software defects
- uncertainty
- human variation
- synergy

SWEBOK v4 (2025, computer.org)

International ISO Standard

specifying the guide to

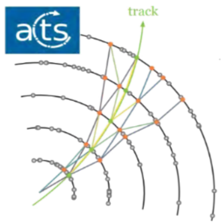
Software Engineering Body of Knowledge

COCOMO II (COst COnstructive MOdel)

Most rigorous statistical analysis of past software projects from historical data

Roadmap for Effective Software Development

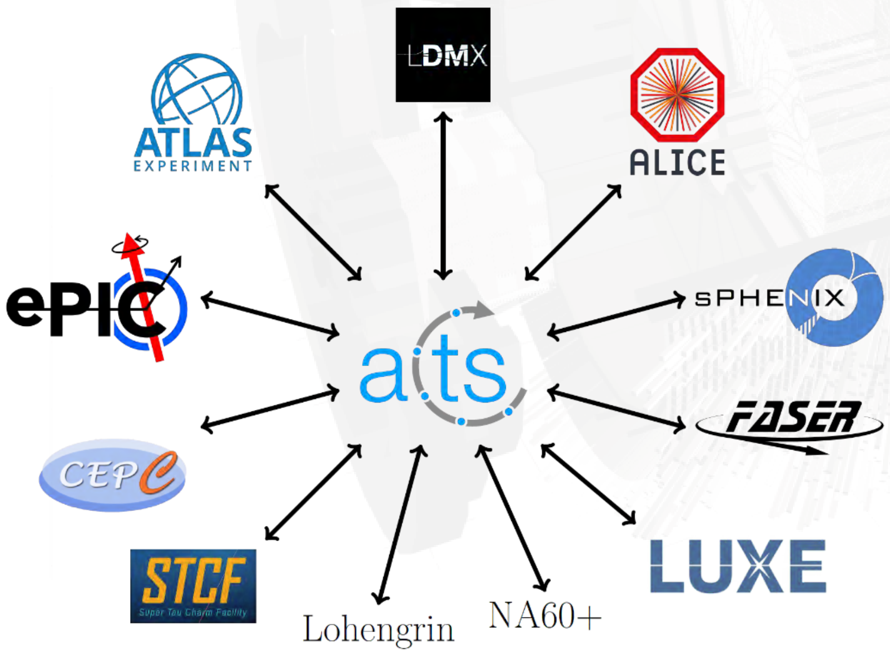
ACTS: A COMMON TRACKING SYSTEM



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.

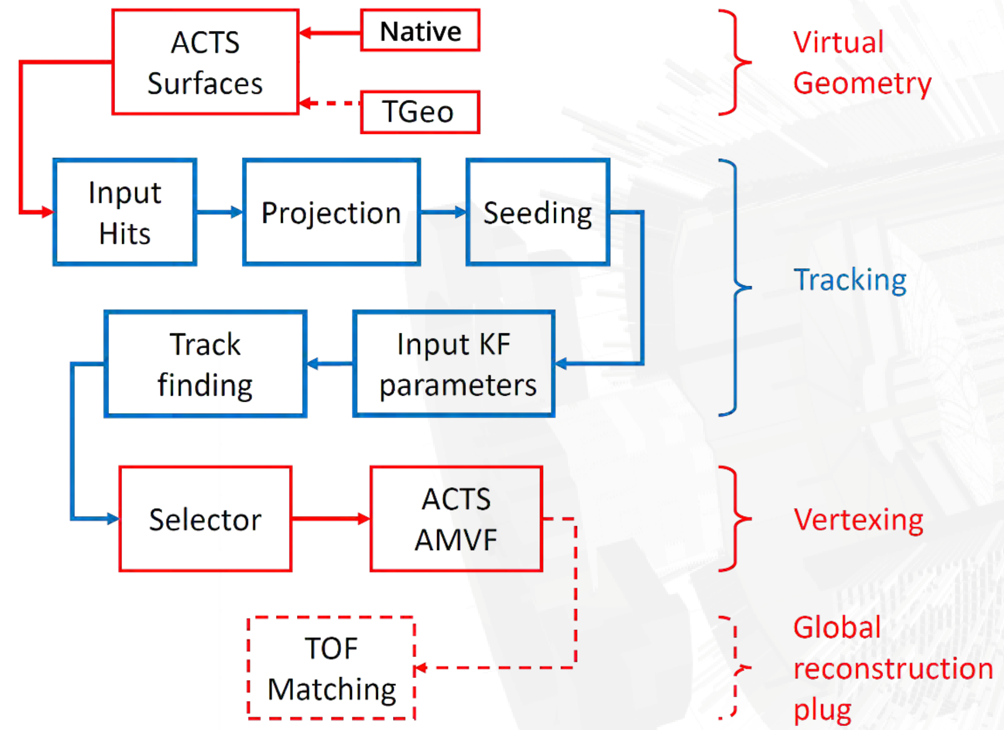
Furthermore, it hosts an umbrella project, called `traccc` that aims to re-implement the standard `Acts` chain for massively parallel hardware. `traccc` relies on the sub libraries:

- 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

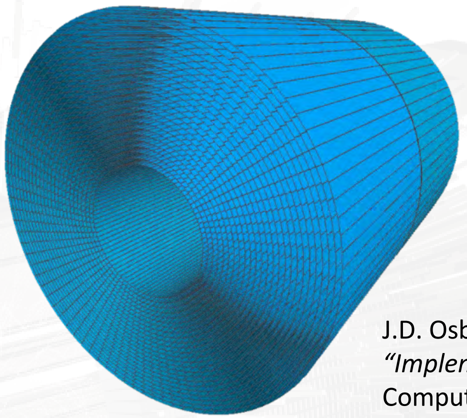
Supported by

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.

ACTS IN MPDROOT



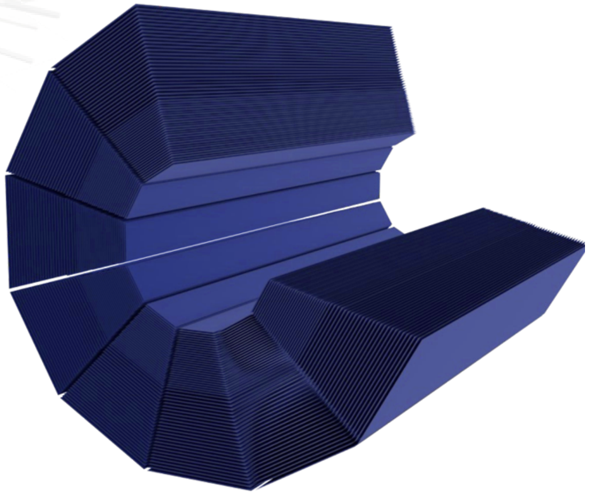
ACTS pipeline in MPDRoot



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, in testing

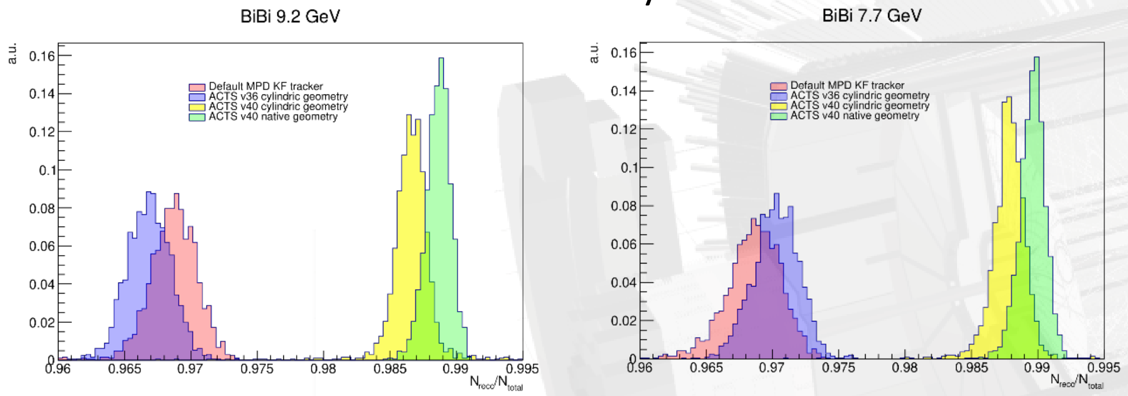


TRACKING EFFICIENCY

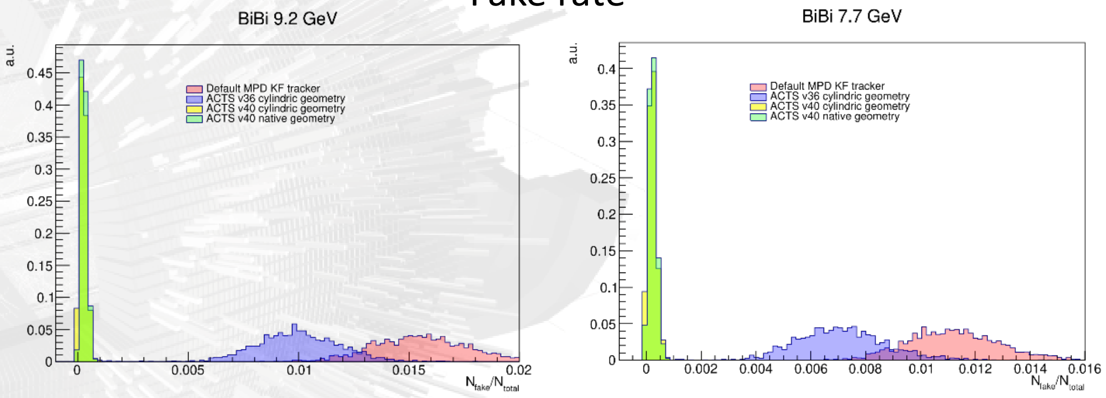
CKF enhancements: much better efficiency, far less fakes
Native geometry: more efficiency improvement

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

Efficiency



Fake rate



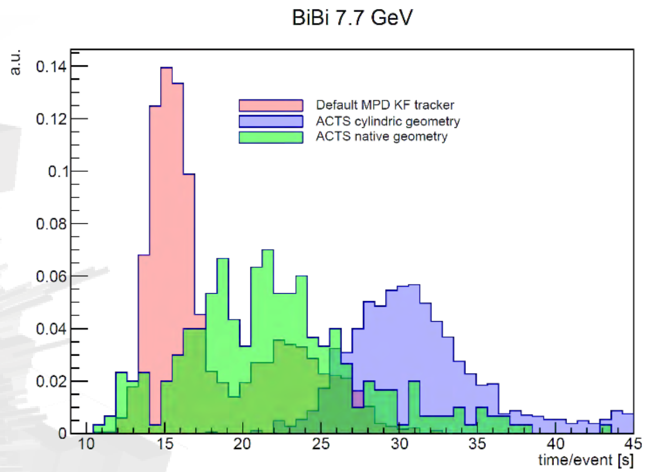
	Default tracker		ACTS v36 cylindric		ACTS v40 cylindric		ACTS v40 native	
	true rate	fake rate	true rate	fake rate	true rate	fake rate	true rate	fake rate
BiBi 9.2 GeV	$\mu = 0.9686$ $\sigma = 0.00212$	$\mu = 0.01544$ $\sigma = 0.002012$	$\mu = 0.9668$ $\sigma = 0.001724$	$\mu = 0.00999$ $\sigma = 0.00189$	$\mu = 0.9866$ $\sigma = 0.001779$	$\mu = 0.00026$ $\sigma = 0.000172$	$\mu = 0.9886$ $\sigma = 0.000922$	$\mu = 0.000275$ $\sigma = 0.000140$
BiBi 7.7 GeV	$\mu = 0.9686$ $\sigma = 0.002107$	$\mu = 0.01122$ $\sigma = 0.001664$	$\mu = 0.9702$ $\sigma = 0.001772$	$\mu = 0.00713$ $\sigma = 0.001612$	$\mu = 0.9878$ $\sigma = 0.001427$	$\mu = 0.000225$ $\sigma = 0.000168$	$\mu = 0.9896$ $\sigma = 0.000976$	$\mu = 0.000229$ $\sigma = 0.000135$

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

MMCP '24 Proceedings, PEPAN

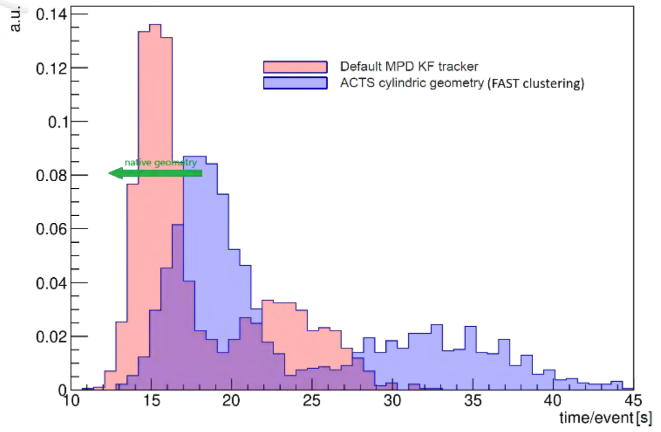
TRACKING SPEED

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 clusterhitfinder – initially written for online event display processing

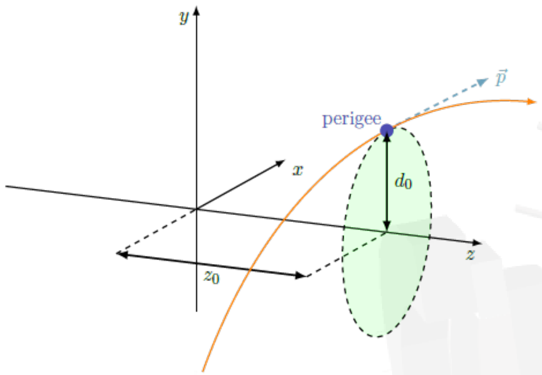
STANDARD + DEFAULT KF	μ = 18.12 s / event	σ = 4.28 s / event
FAST + ACTS cylindric geometry	μ = 23.41 s / event	σ = 7.48 s / event
FAST + ACTS native geometry	?	?



FAST v0.2.0 (2023y) + ACTS cylindric geometry … 25% speedup, efficiency issues

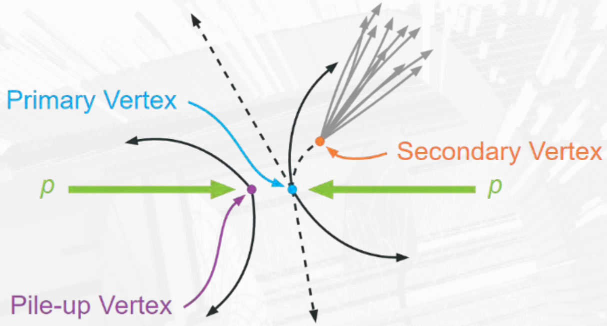
FAST v2.0.8 (2025y) + ACTS native geometry … port ready soon (~1 month of work), new combo should be superior in **all** aspects: speed, efficiency, resource usage, maintainability

ACTS PRIMARY VERTEXING

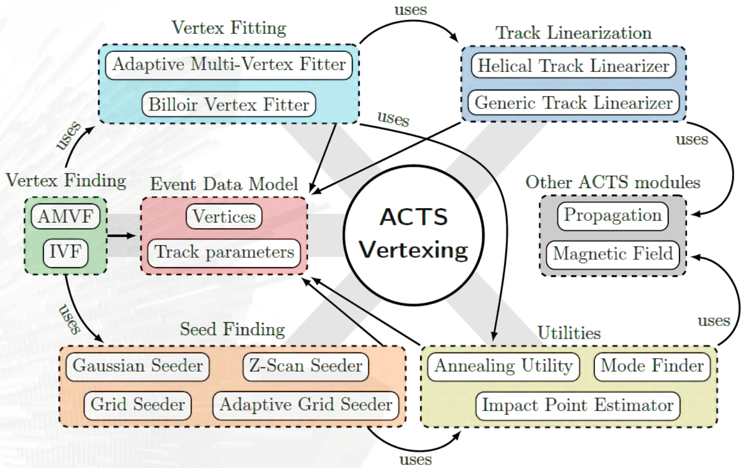


PERIGEE TRACK PARAMETRIZATION
Track selection: |d_0| < 2mm

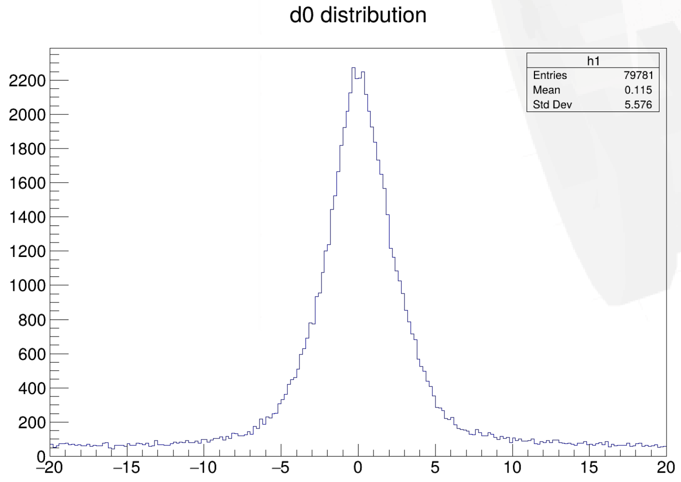
ACTS VERTEXING SUITE



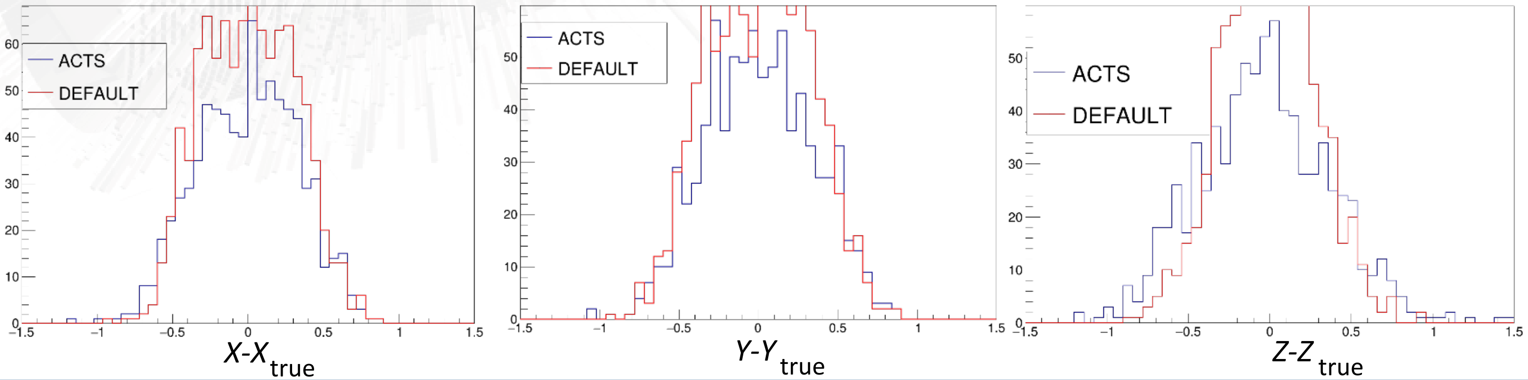
- many tunable parameters



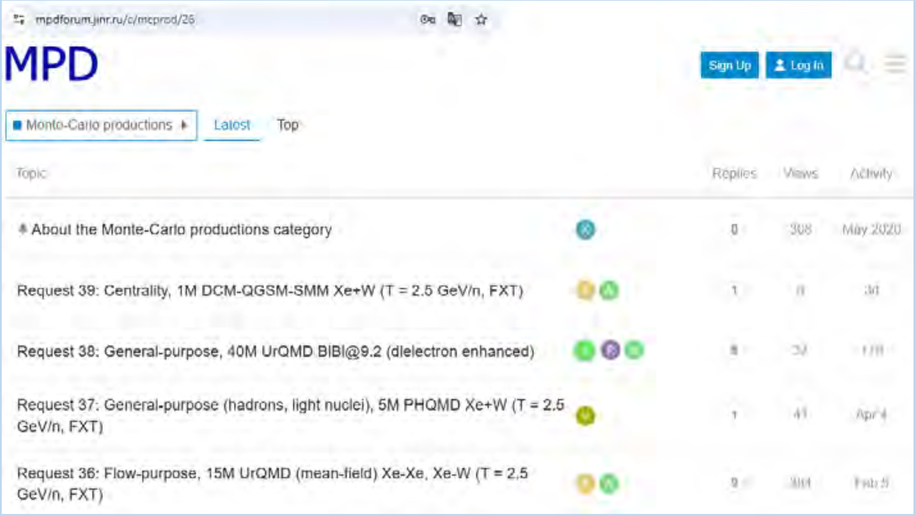
Schlag S. "Advanced algorithms and software for primary vertex reconstruction and search for flavor-violating supersymmetry with the ATLAS experiment." Dissertation, Johannes Guttenberg-Universitaet Mainz, 2022.



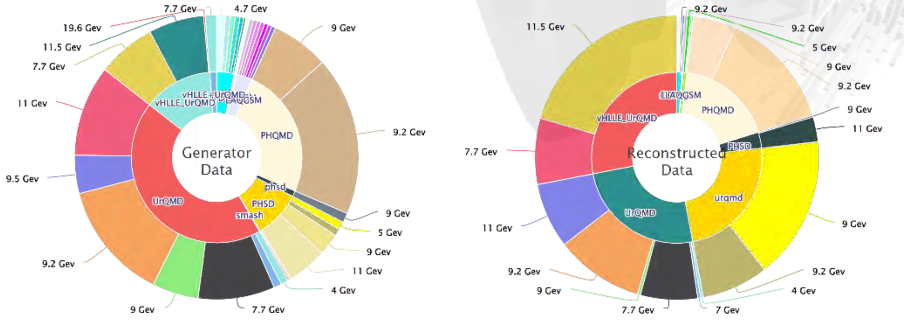
1000 events, BOX generator



MASS PRODUCTION



MPD Monte-Carlo DB stats
http://db-nica.jinr.ru/mpdmc



Generator	PWG	Coll.	$\sqrt{s}$	# of events(10^6)	Reco
UrQMD	PWG4	AuAu	11	15	+
		BiBi	9	10	+
			9.46	10	+
			9.2	135	+
	PWG2	AuAu	11	10	+
	PWG3	AuAu	7.7	10	+
		BiBi	7.7	10	+
			9	15	+
		pp	9	10	+
		BiBi fix target	2.5	12	+
		BiBi fix target	3.0	12	+
		BiBi fix target	3.5	12	+
		XeW fix target	2.5	15	+
		XeXe fix target	2.5	15	+
	PWG1	BiBi	9.2	76	+
DCM-SMM	PWG1	BiBi	9.2	2	+
PHQMD	PWG2	BiBi	8.8	15	+
			9.2	61	+
			2.4/3.0/4.5	10/10/2	-
vHLLE-UrQMD	PWG3	BiBi	11.5	15	+
		AuAu	11.5	15	+
		AuAu	7.7	20	+
		BiBi	9.2	48	+
Smash	PWG1	BiBi	9.46	10	+
		ArAr	4/7/9/11	20/20/20/20	-
		AuAu	4/7/9/11	20/20/20/22	-
		XeXe	4/7/9/11	20/20/20/20	-
		CC	4/7/9/11	20/20/20/20	-
		pp	4/7/9/11	50/50/50/50	-
JAM	PWG3	AuAu	3/3.3/3.5/3.8/4.0/4.2/4.5/5	40/40/40/40/40/40/40	
DCM-QGSM-SMM	PWG3	AuAu	4/9.2	5/5	+
		AgAg	4/9.2	5/5	+
		BiBi	4/9.2	5/6	+
PHSD		BiBi	9/9.2	25	+
Total				1453	609

Total amount of generated data is around 1.8 PB, 39 mass productions were done.

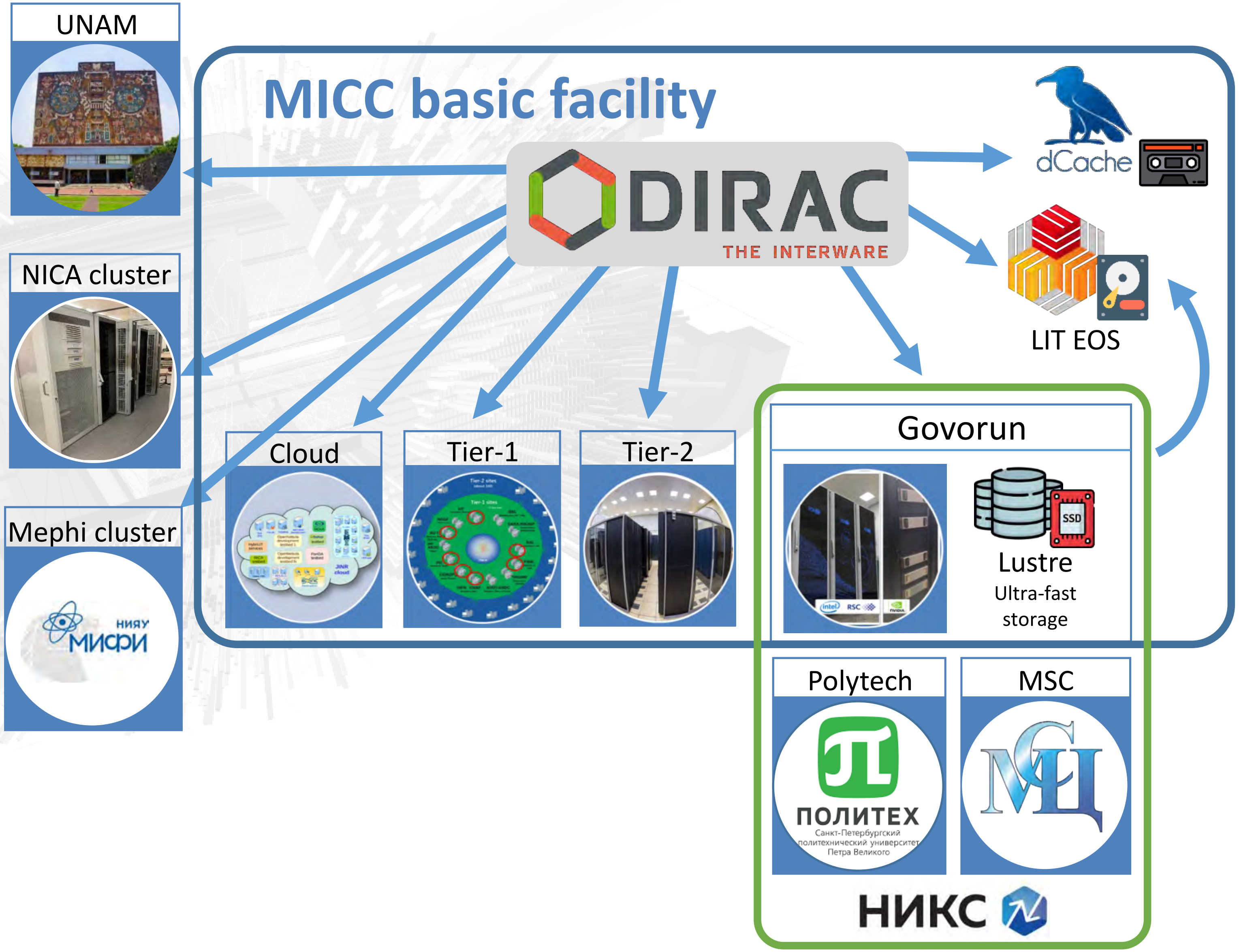
Moshkin A., Pelevanyuk I., Alexandrov I., Alexandrov E.

MPD COMPUTING

- NICA offline cluster 1000 cores(limit for users)
- GOVORUN up to 3260 cores in last production
- Tier1 1500 cores
- Tier2 1000 cores
- Clouds(JINR and JINR Member States) 70 cores
- UNAM(Mexico University) 100 cores
- National Research Computer Network of Russia (now resources from SPBTU and JSCC) 672 cores

Mass production storages integrated in Dirac File Catalog have size 9,2 PB.

More information:
Kutovskiy,N., Mitsyn, V., Moshkin, A. *et al.* Integration of Distributed Heterogeneous Computing Resources for the MPD Experiment with DIRAC Interware. *Phys. Part. Nuclei* **52**, 835–841 (2021)
V. Korenkov *et al* 2023 *J. Phys.: Conf. Ser.* **2438** 012029



NEAR FUTURE

TRACKING

- Fast clustering v2.0.8 ACTS integration
- Global integration
- Testing & feedback from analysis groups

EXPERIMENT NEXT YEAR

- Online QA histograms
- Microservices, k8s
- Digitizer integration
- Event viewer
- Detector calibration

SOFTWARE DEVELOPMENT

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

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

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Thank You !

Q & A