Software development for the NICA experiments: MpdRoot & BmnRoot

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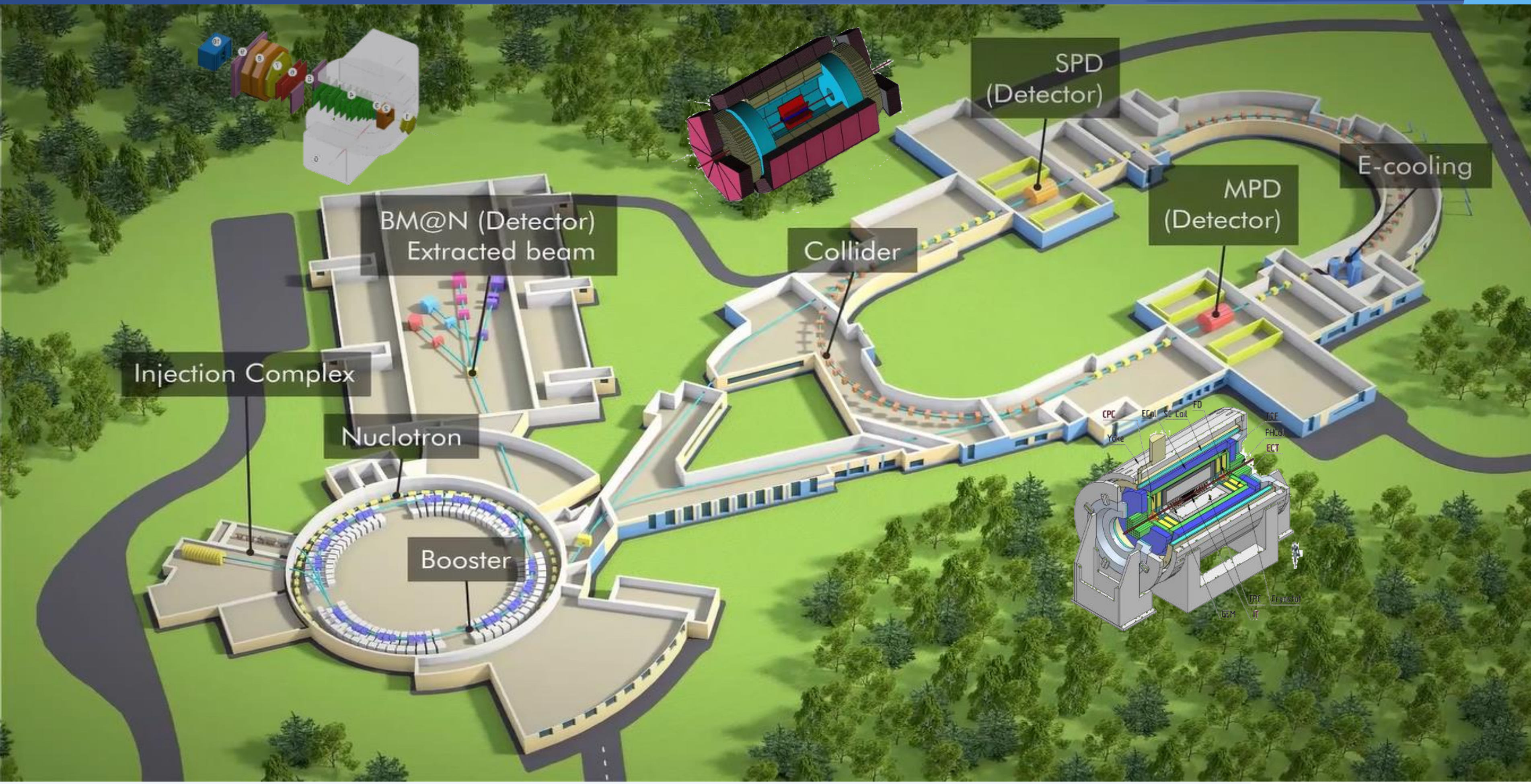
on behalf of the MPD & BM@N collaboration

9 July 2018

Nuclotron-based Ion Collider fAcility



- Beams: from $p, d^{\uparrow}$ to Au^{79+}
- Luminosity: 10^{27} (Au^{79+}), 10^{32} (p) $cm^{-2}s^{-1}$
- Collision energy: $\sqrt{S_{NN_{AU}}}$ = *4 – 11 Gev* E_{lab} = *1 – 6 AGev*

- Fixed target experiment: BM@N (2018)
- 2 interaction points: MPD (2020) & SPD
- Official site: *nica.jinr.ru*

Simulation and analysis steps of experiments

UrQMD
LAQGSM
Pythia…

Geant3
Geant4
Fluka…

should be covered by software of the experiments!

Event generator → **Simulation** → **Digitization** → **Reconstruction** → **Analysis**

Event generator	**Simulation**	**Digitization**	**Reconstruction**	**Analysis**
simulate physics process (quantum mechanics and probabilities)	simulate interaction with media and detector materials	translate interactions with detectors into clusters of signals	as for experimental data	as for experimental data

- ✓ Interaction of interest
- ✓ Geometry of the system
- ✓ Materials used
- ✓ Particles of interest
- ✓ Generation of test events of particles
- ✓ Interactions of particles with matter and EM fields
- ✓ Response to detectors
- ✓ Records of energies and tracks
- ✓ Analysis of the full simulation at whatever detail you like
- ✓ Visualization of the detector system and tracks

- ✓ Clustering
- ✓ Hits reconstruction in subdetectors
- ✓ Tracks reconstruction
- ✓ Searching for track candidates in main tracker
- ✓ Track propagation using Kalman filter
- ✓ Matching with other detectors
- ✓ Vertex finding
- ✓ Particles identification

- ✓ Phases of QCD matter at high baryon density
- ✓ Hydrodynamics and hadronic observables
- ✓ Femtoscopy, correlations and fluctuations
- ✓ Local P and CP violation in hot QCD matter
- ✓ Cumulative processes
- ✓ Polarization effects and spin physics
- ✓ Hypernuclei production in heavy ion collisions
- ✓ and many others…

start from scratch?

FairRoot Framework

The FairRoot package is an object-oriented simulation, reconstruction and data analysis framework based on ROOT. It includes core services for detector simulation and data analysis for HEP experiments. The framework delivers base classes which enable the users to easily construct experimental setup in a fast and convenient way. By using the Virtual Monte Carlo concept it is possible to perform the simulations using either Geant3 or Geant4 without changing the user code or the geometry description.

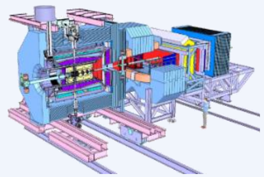
https://fairroot.gsi.de/

The basic idea of FairRoot is to provide a unified package with generic mechanisms to deal with most commonly used tasks in HEP. FairRoot allow physicists to:

- Focus on physics deliverables while reusing pre-tested software components.
- Do not submerge into low-level details, use pre-built and well-tested code for common tasks.
- Allows physicists to concentrate on detector performance details, avoiding purely software engineering issues like storage, retrieval, code organization etc.

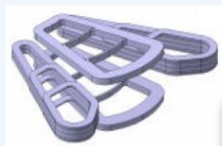
FairRoot Universe

Start testing the VMC concept for CBM

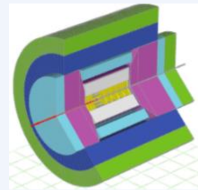


Panda decided to join → oct.

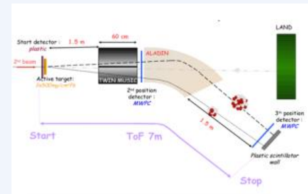
FairRoot: base package for experiments



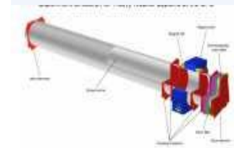
R3B joined



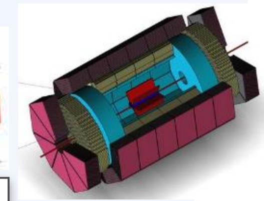
EIC (Electron Ion Collider BNL)



SOFIA (Studies On Fission with Aladin)



SHIP (Search for Hidden Particles)

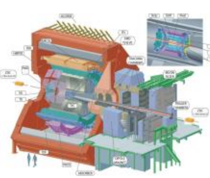


SPD@NICA joined

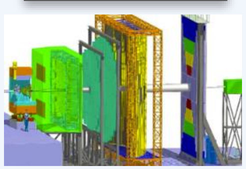
2004 | 2006 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015

ALICE

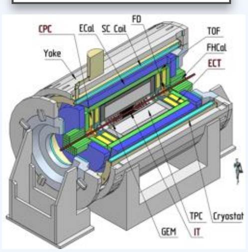
FAIR



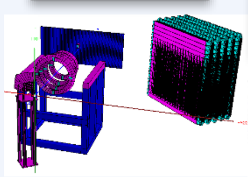
First Release of CbmRoot



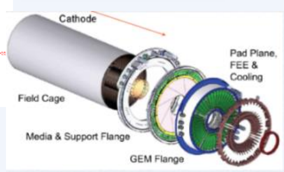
MPD@NICA started with FairRoot



ASYEOS joined



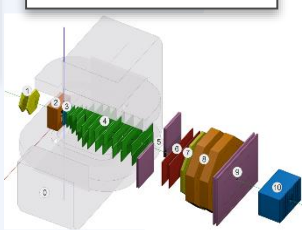
GEM-TPC seperated from PANDA branch



ENSAR-ROOT

Collection of modules used by structural nuclear phsyics exp.

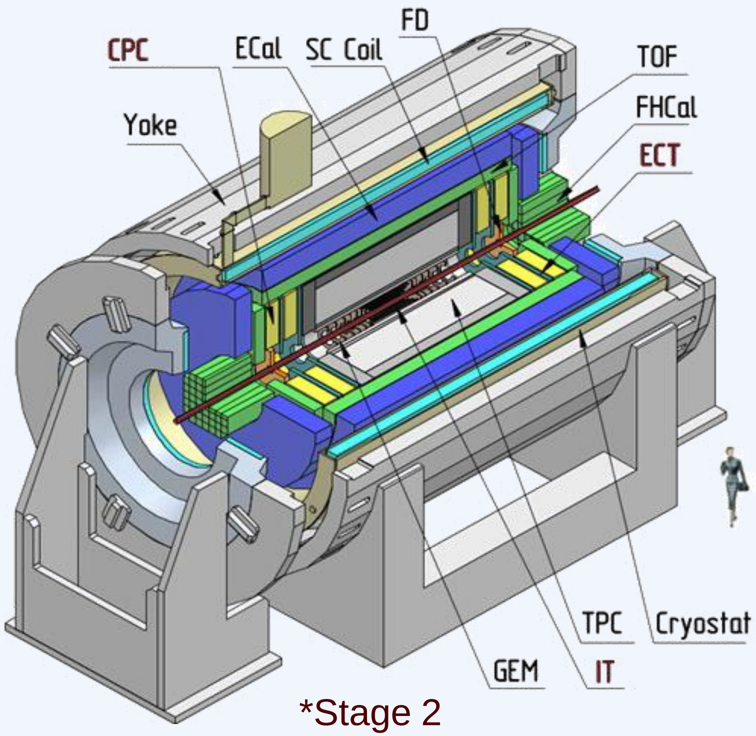
BM@N@NICA started with FairRoot



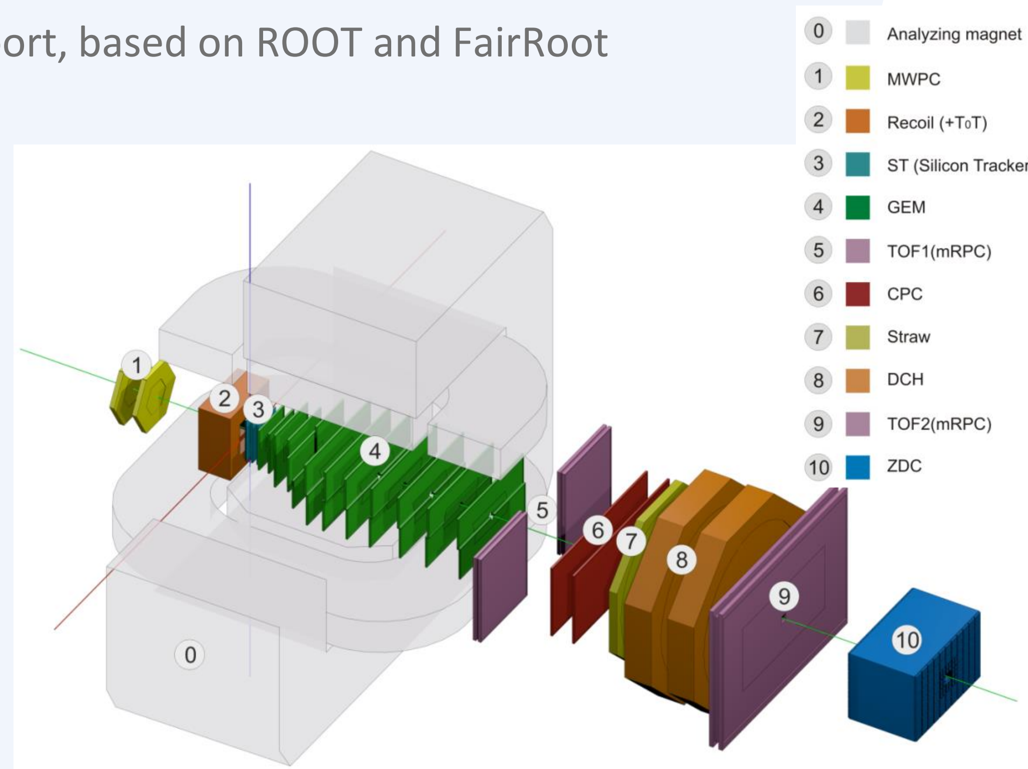
MpdRoot and BmnRoot software

The software MpdRoot and BmnRoot are developed for the MPD and BM@N event simulation, reconstruction of experimental or simulated data and following physics analysis of heavy ion collisions registered by the detectors.

C++ classes, Linux OS support, based on ROOT and FairRoot



*Stage 2



MpdRoot and BmnRoot are available in the GitLab@JINR https://git.jinr.ru/nica/

MpdRoot & BmnRoot design

- Use FairSoft external packages

ROOT, XRootD, Pythia, PLUTO, HepMC, MillePede, Geant3/4, VGM, GSL, boost…

- Use FairRoot as a set of base classes and modules of needed by particle experiments

- Extended set of event generators for collisions:

UrQMD, Hybrid UrQMD, vHLLE + UrQMD, QGSM/LAQGSM, HSD/pHSD, HADGEN, 3 Fluid Dynamics, PLUTO

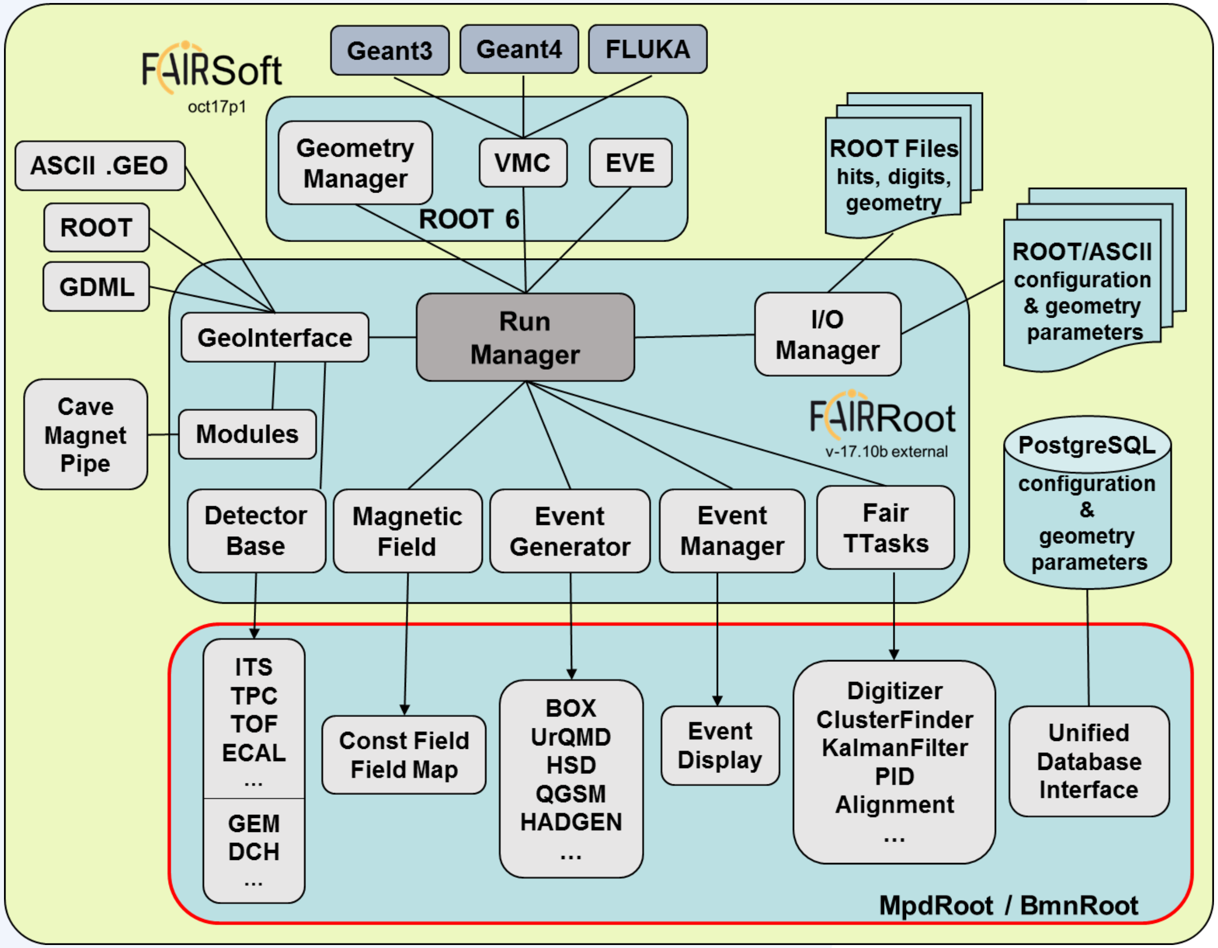
simple (for testing) - BOX, ION, PART

- Experiment-specific parts and geometry are developed for each detector independently

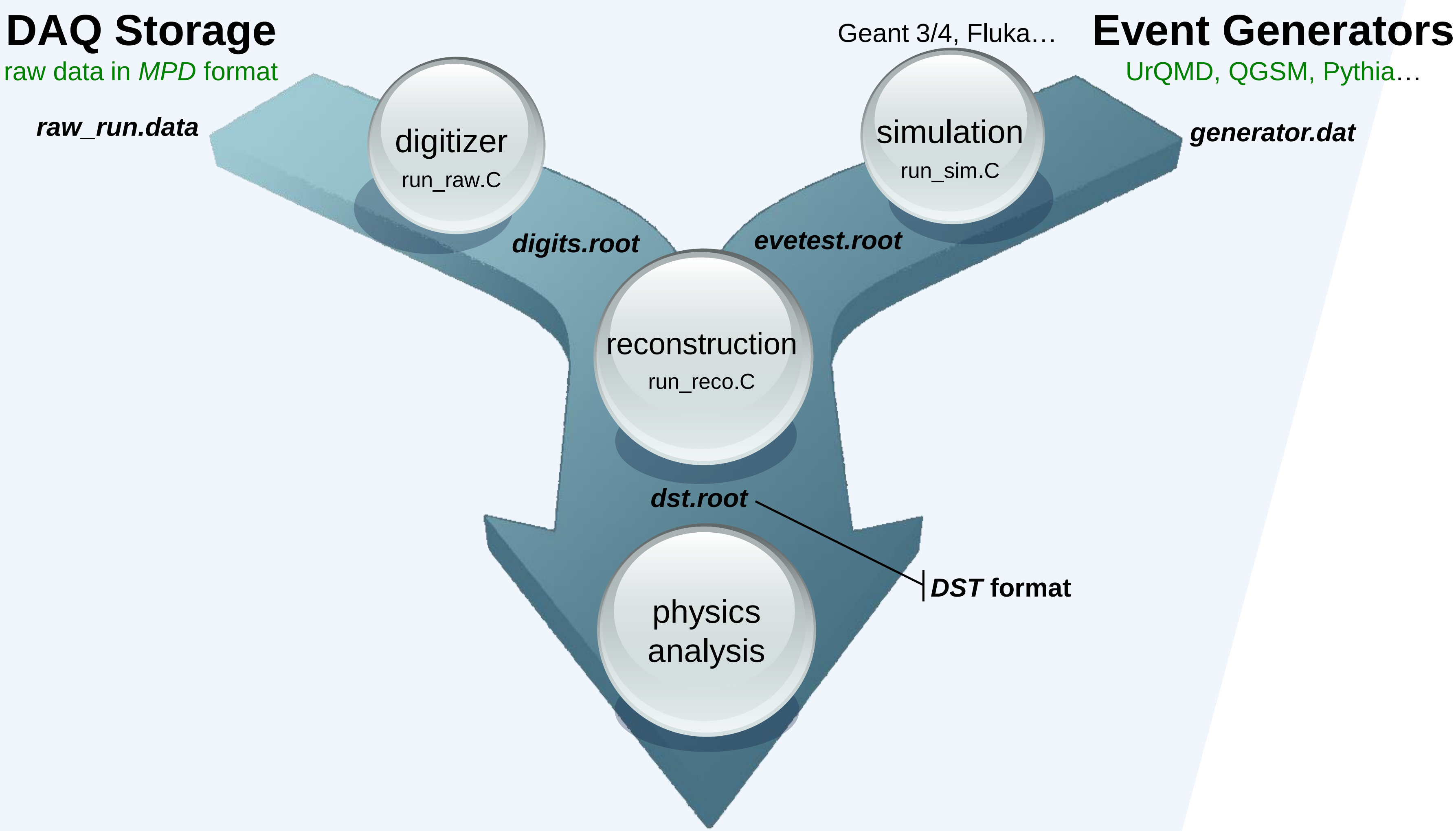
- Particle propagation by GEANT3 & GEANT4

- Advanced detector response functions, realistic tracking, PID were included

MPD and BM@N homepage: http://mpd.jinr.ru



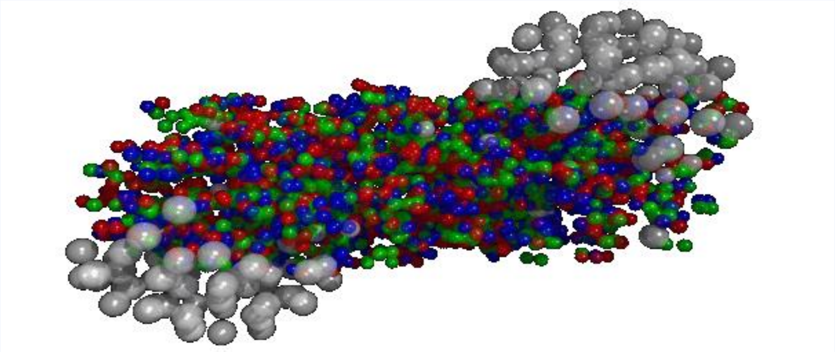
MpdRoot & BmnRoot data processing

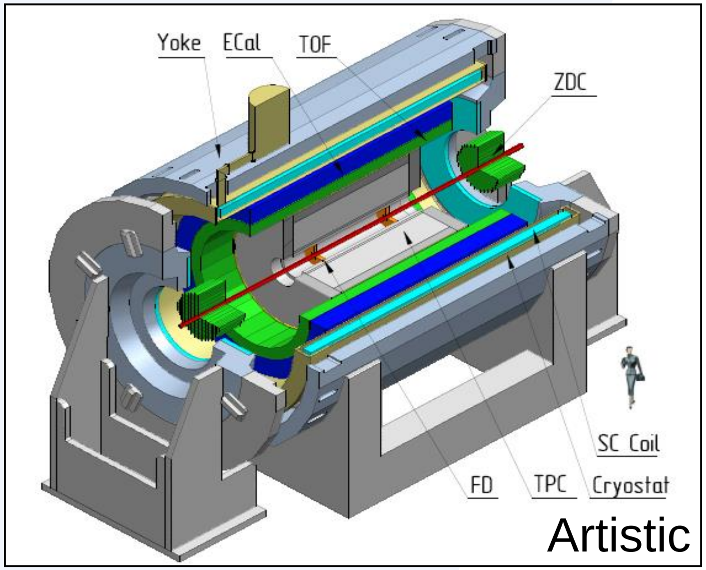


MPD geometry & simulation

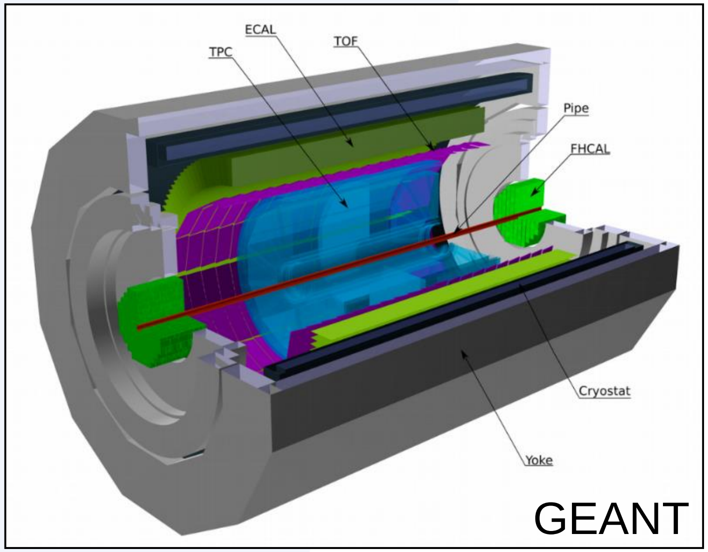
extended set of event generators for collisions

- Ultrarelativistic Quantum Molecular Dynamics (UrQMD)
- Quark Gluon String Model (QGSM, LAQGSM) } nuclear fragments
- Shield (on fly) }
- Parton Hadron String Dynamics (HSD/PHSD) } flows
- Pluto }
- Hybrid UrQMD } femtoscopy
- vHLLE+UrQMD }
- 3 Fluid Dynamics model (Theseus) } baryon stopping power





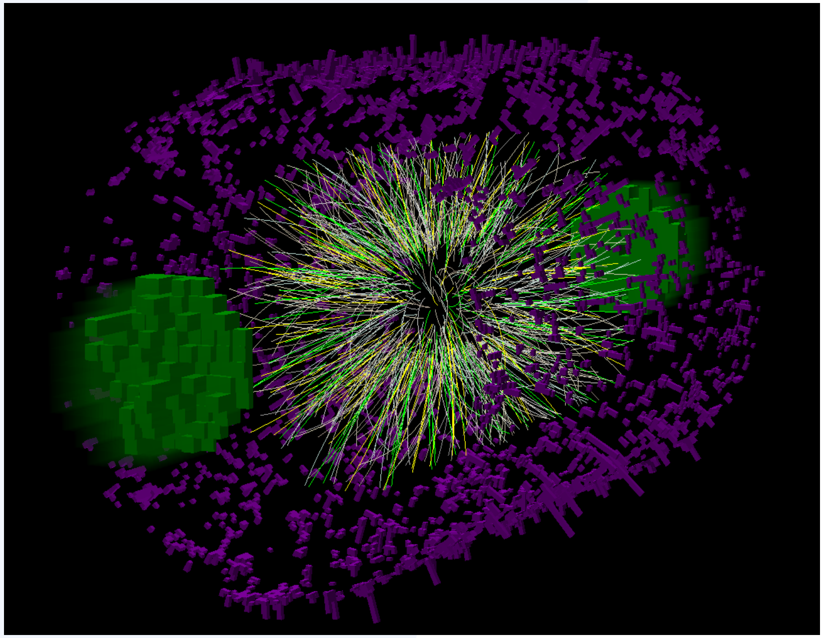
Artistic



GEANT

MpdRoot. Event reconstruction

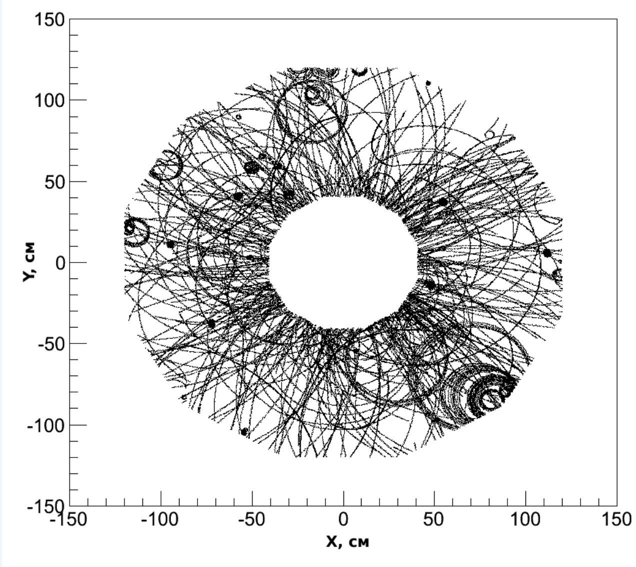
1. **Hit reconstruction in subdetectors.**
2. **Track reconstruction.**
   - Searching for track-candidates in main tracker
   - Track propagation, e.g. using the Kalman Filter
   - Matching with other detectors (global tracking)
3. **Vertex finding.**
4. **Particle identification.**

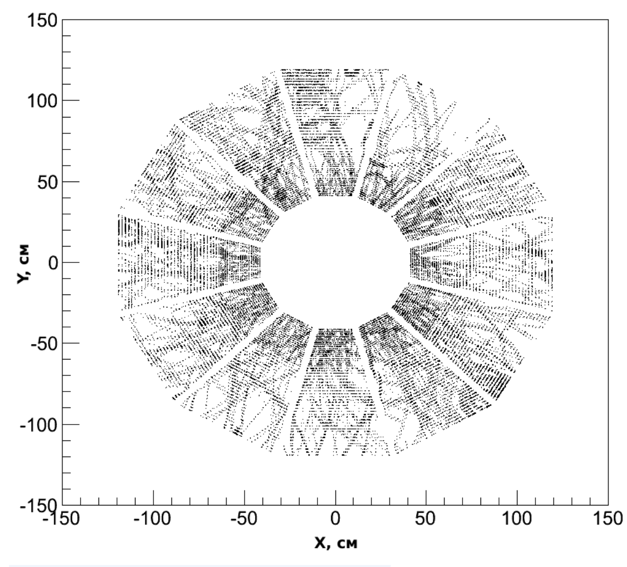


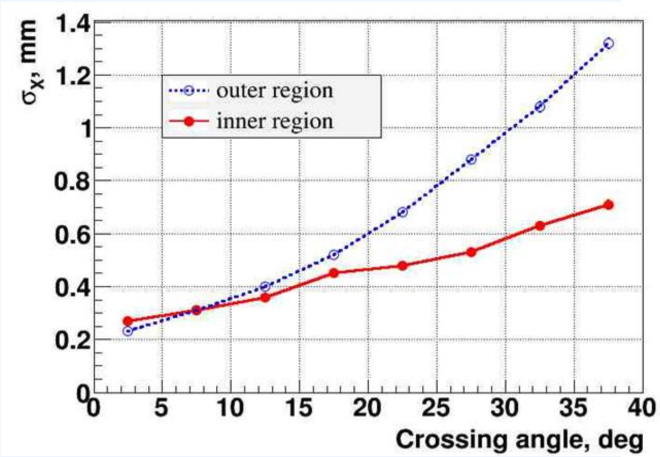
MpdRoot. Clustering in TPC

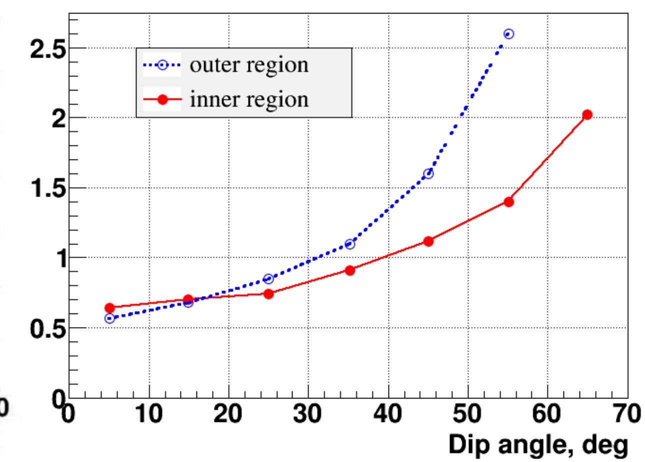
The hit reconstruction algorithm contains the following main steps:

1) Searching for extended clusters in (Pad-Time) for each pad raw.
2) Searching for peaks in time-profile for each pad in the found extended cluster.
3) Combining the neighboring peaks into resulting hits.



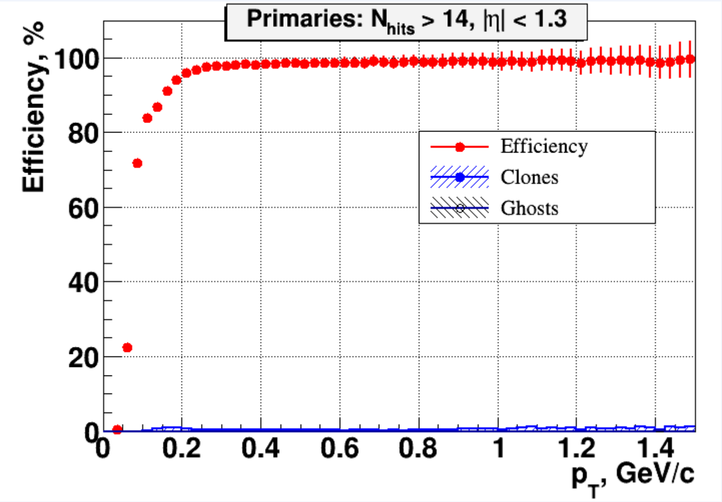




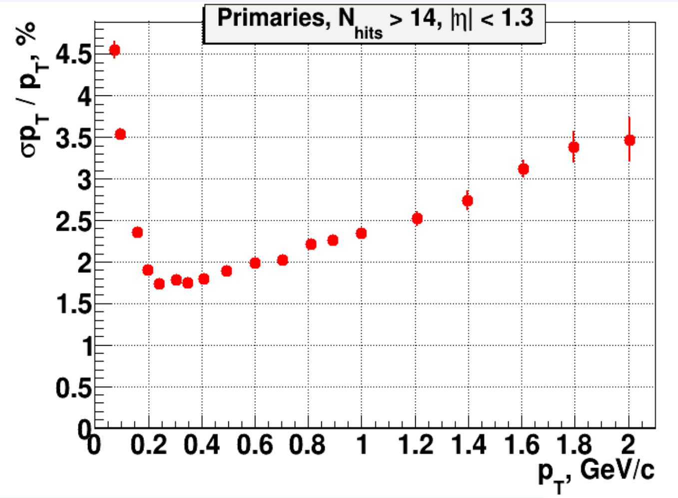


MpdRoot. Tracking

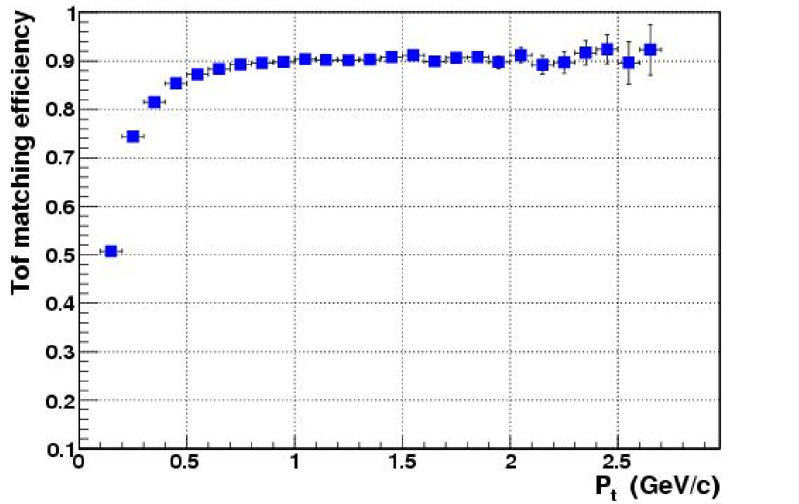
TPC tracking efficiency



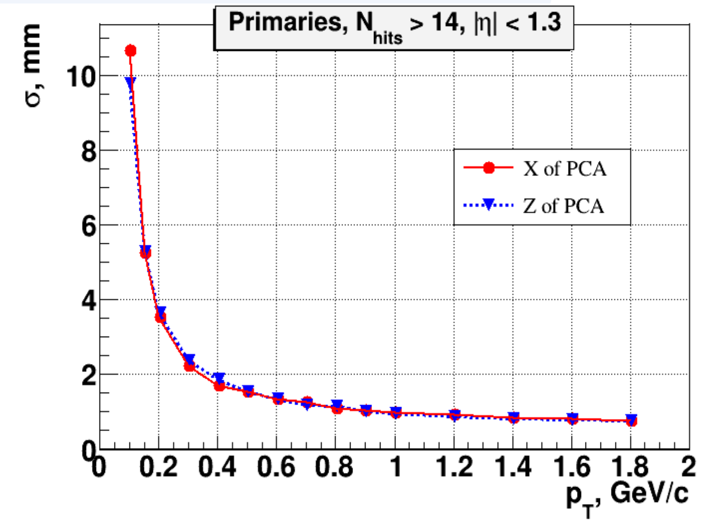
Transverse momentum resolution



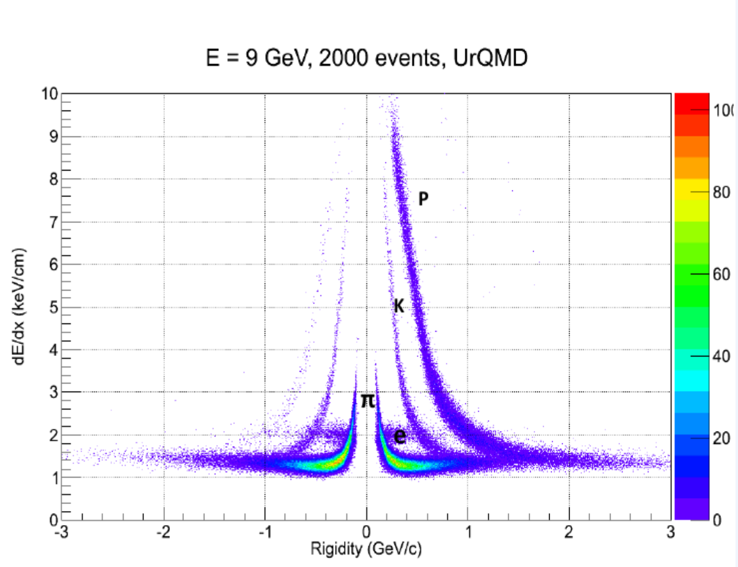
Efficiency of TOF matching



Primary vertex resolution



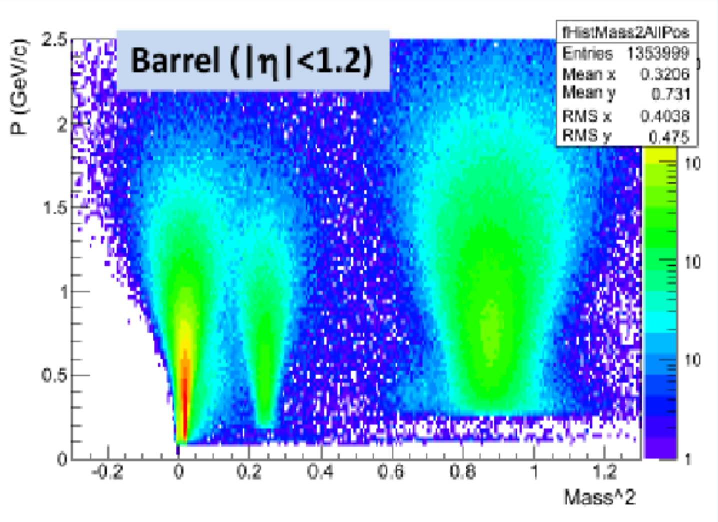
MpdRoot. Particle identification

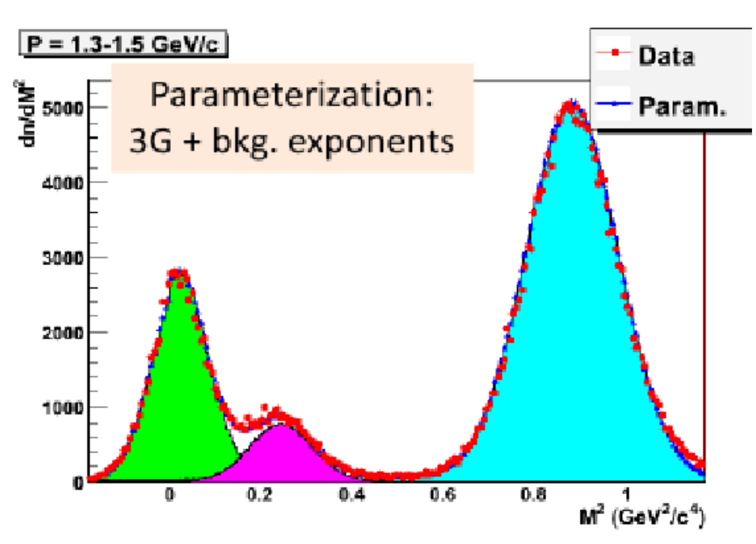


TPC
PID: Ionization loss (dE/dx)
BBF + Aleph parametrization
Separation:
e/h – 1.3..3 GeV/c
π/K – 0.1..0.6 GeV/c
K/p – 0.1..1.2 GeV/c

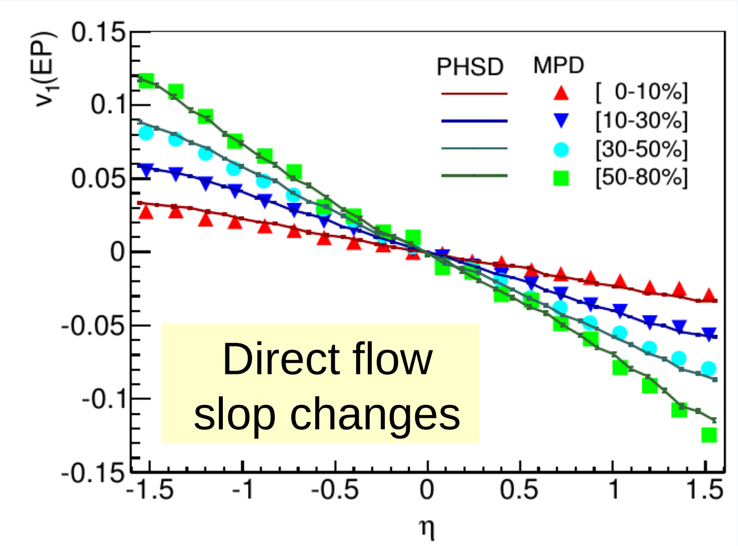
MPD PID (TOF):

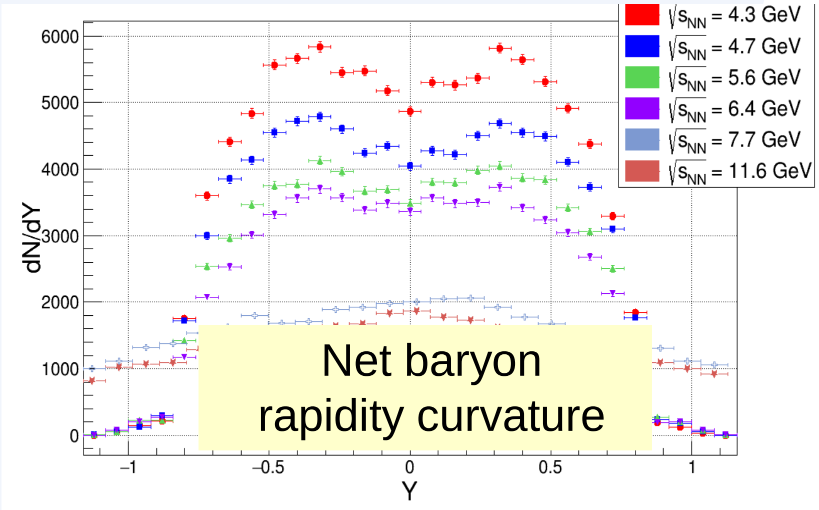
- π/K separation up to p=1.7 GeV/c, above 2 GeV/c - extrapolating the fitted 3G parameters
- Protons up to 3 GeV/c
- dE/dx provide extra PID capability for electrons and low momentum hadrons

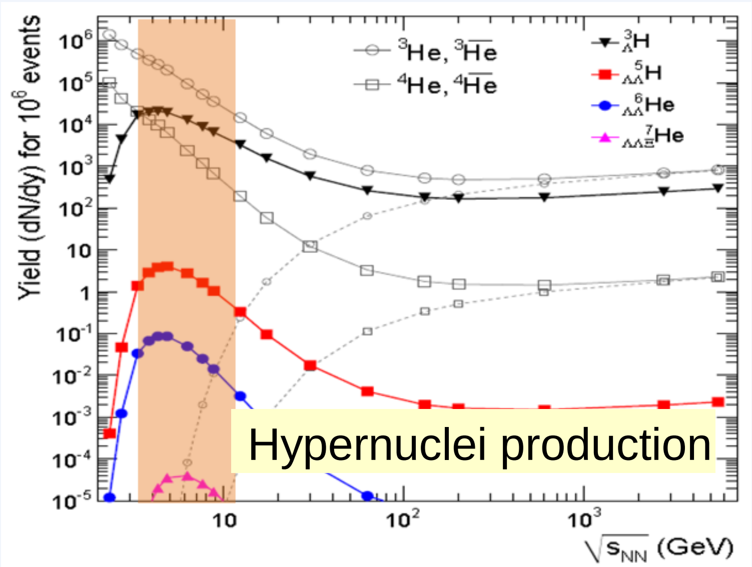


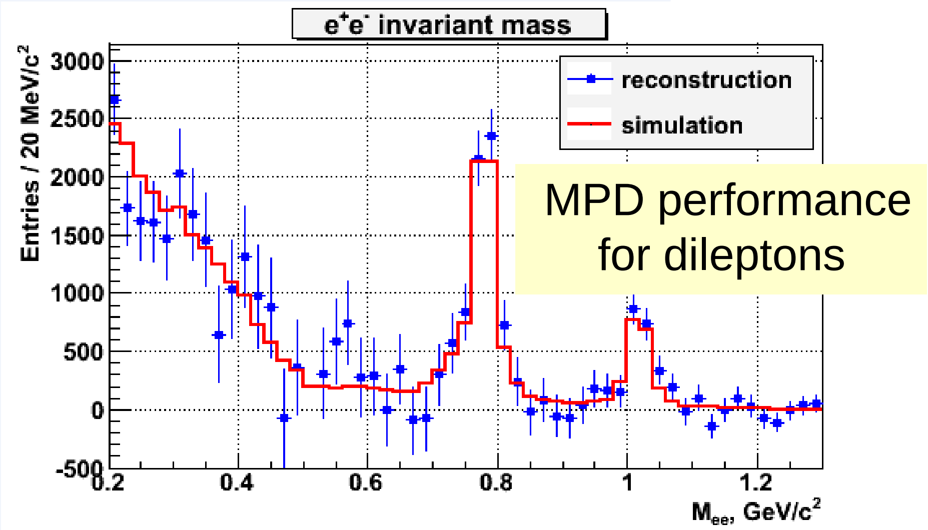


MPD physics with the MC generators





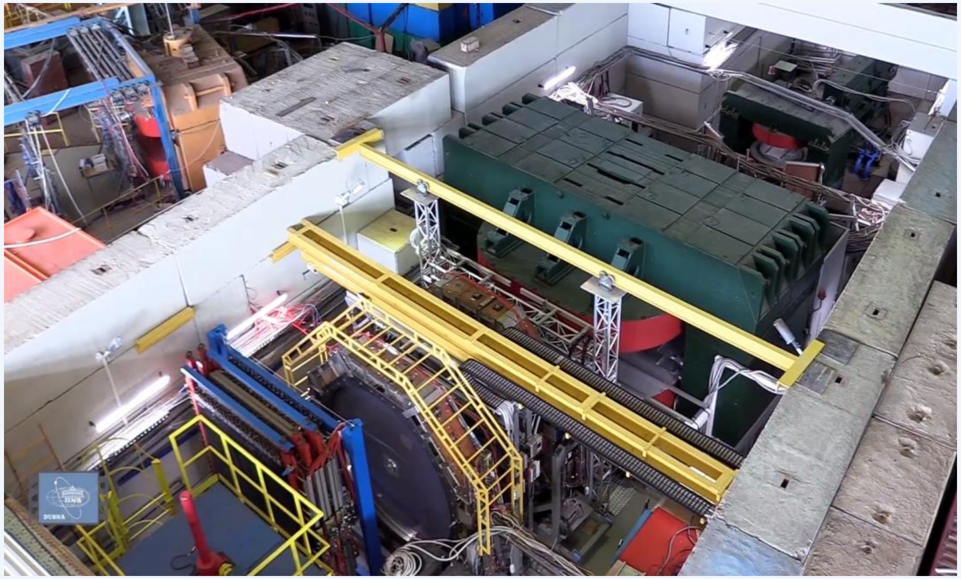




P. N. Batyuk, V. D. Kekelidze, V. I. Kolesnikov, O. V. Rogachevsky, A. S. Sorin, V. V. Voronyuk. Feasibility study of heavy ion physics program at NICA // Physics of Particles and Nuclei 47:4, 2016, 540-566

BM@N in Nuclotron runs (2015 – 2018)

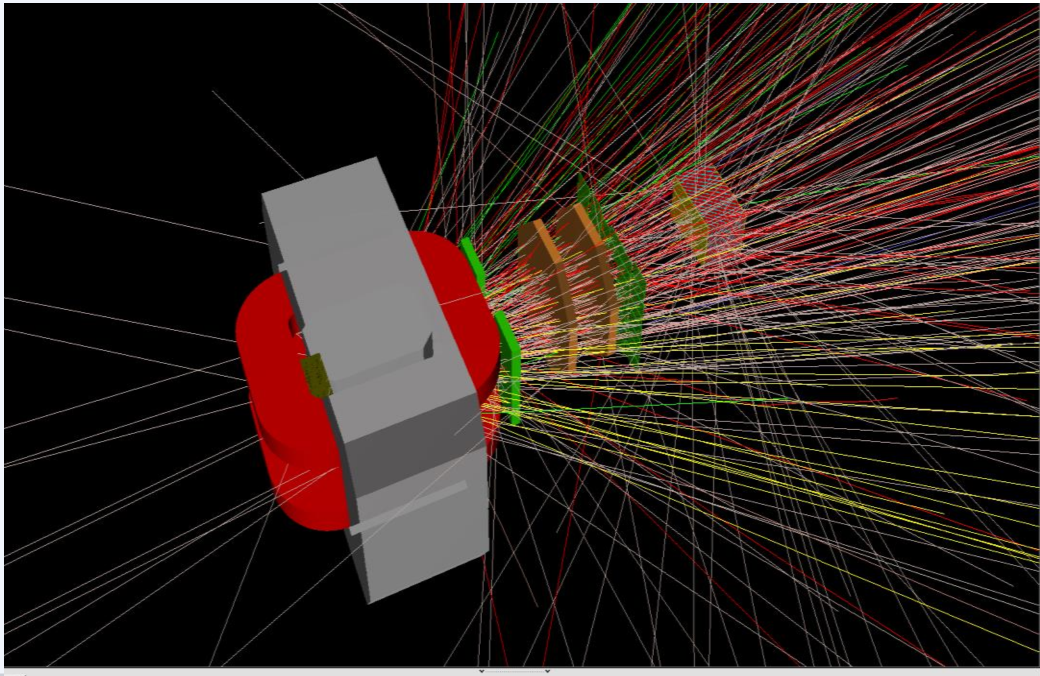
❖ **Run – 51** (d,C)		*Feb. 22 – Mar. 15,* ***2015***
❖ **Run – 52** (d)		*June 29 – June 30,* ***2016***
❖ **Run – 53** (d, d$^{\uparrow}$)	***Technical***	*Dec. 9 – Dec. 23,* ***2016***
❖ **Run – 54** (C)		*Mar. 7 – Mar. 18,* ***2017***
❖ **Run – 55** (C,Ar,Kr)	***Technical / Physical***	*Mar. 3 – Apr. 5,* ***2018***



- Beams: deutron (4 AGeV), $\mathbf{C^{12}}$ (3.5–4.5 AGeV), Ar (3.2 AGeV), Kr (2.4, 3.0 AGeV)
  Targets: C, Cu, Pb, Al, Sn, C_2H_4, H_2 or empty
- Trace beams, measure beam profile and time structure
- Test integrated DAQ, T_0 and Trigger system
- Detectors: MWPC, Si, GEM, ToF-400, DCH-1, DCH-2, ToF-700, ZDC, ECAL, LAND
- Detect min bias beam-target interactions to reconstruct hyperons, identify charged particles and nucleus fragments

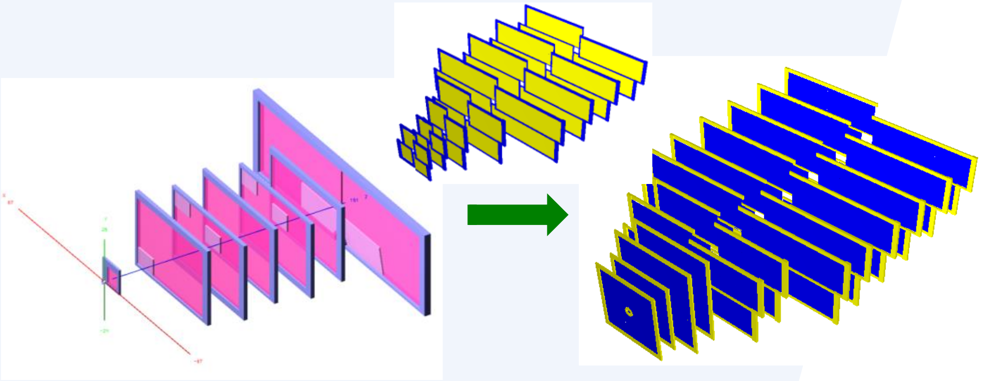
BmnRoot. Event reconstruction

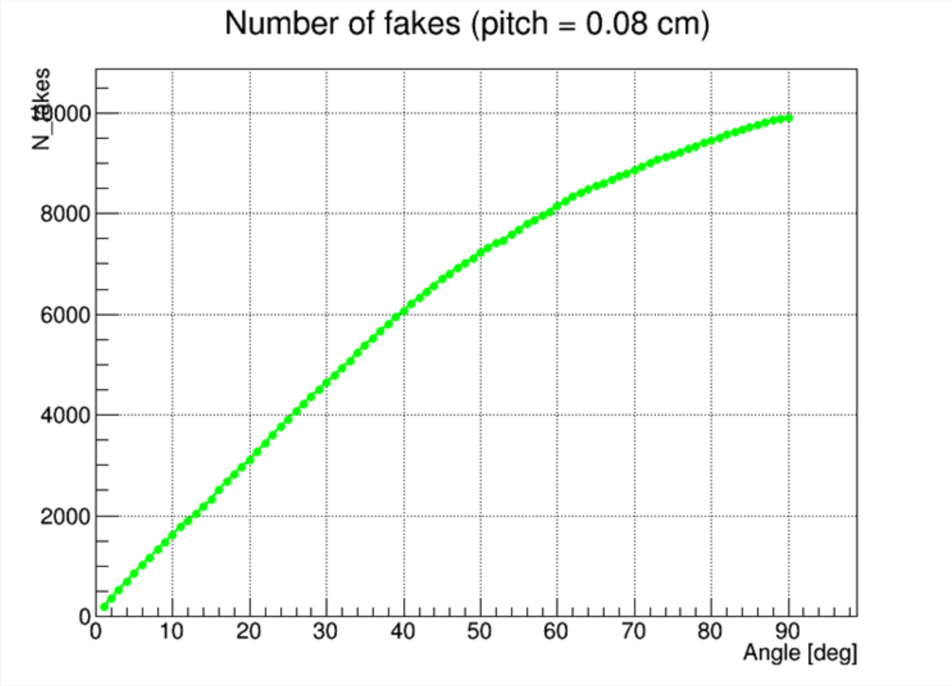
1. **Hit reconstruction in subdetectors.**
2. **Track reconstruction.**
   - Searching for track-candidates by Kalman Filter in the GEM
   - Track propagation in the GEM using Kalman Filter
   - Matching of TOF-hits & DCH-hits with the GEM-tracks (global tracking)
3. **Vertex finding.**

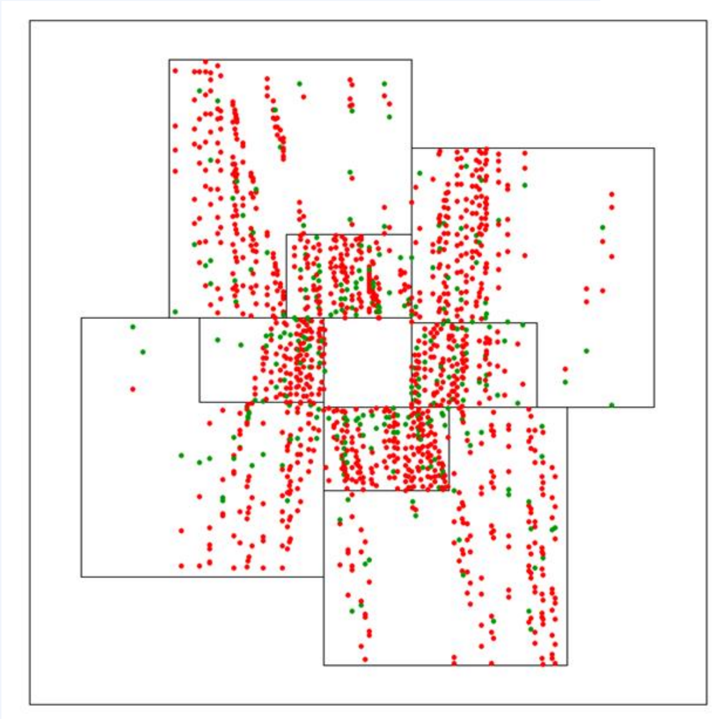


BmnRoot. Clustering in GEM

- There are realistic hit finder in GEMs
- For the GEM stations procedure of the fake hits production is implemented



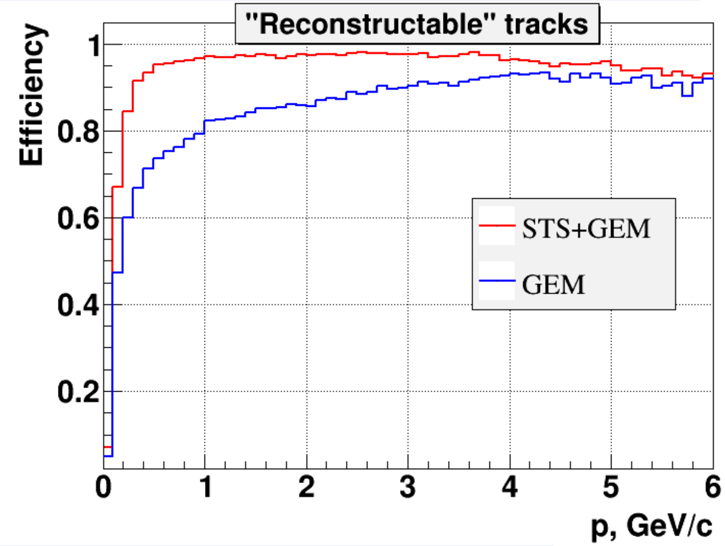


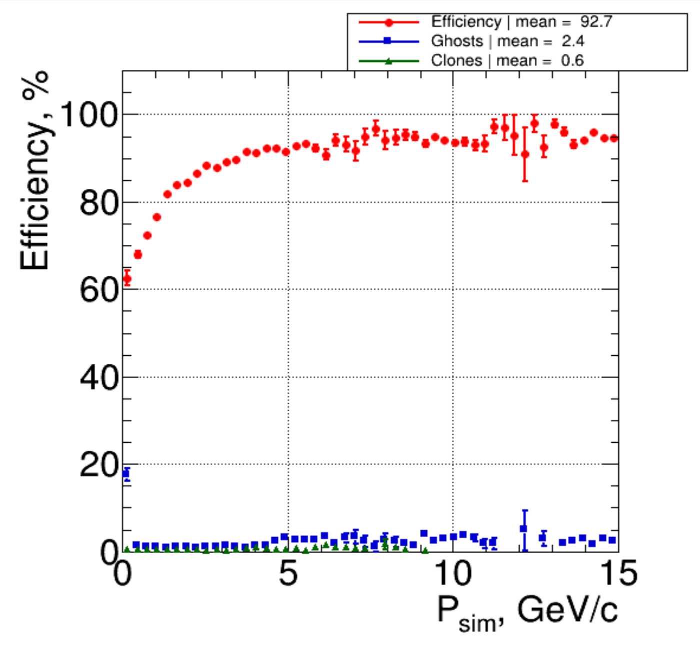


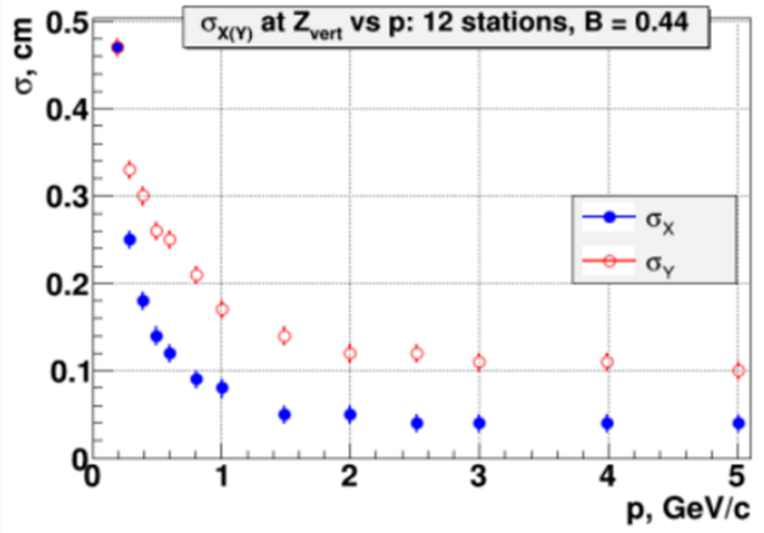
BmnRoot. Tracking in GEM

In BmnRoot there are two independent branches of tracking in GEMs:

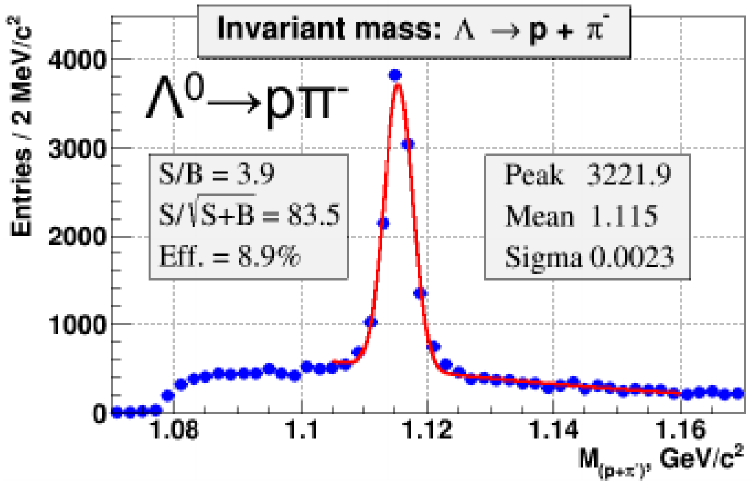
1) The first tracking is based on the L1-tracking (CBM@GSI). Track-candidates are searched by the cellular automatons.
2) The second tracking is based on 3D conformal mapping. Track-candidates are searched by the developed special coordinate transformation.



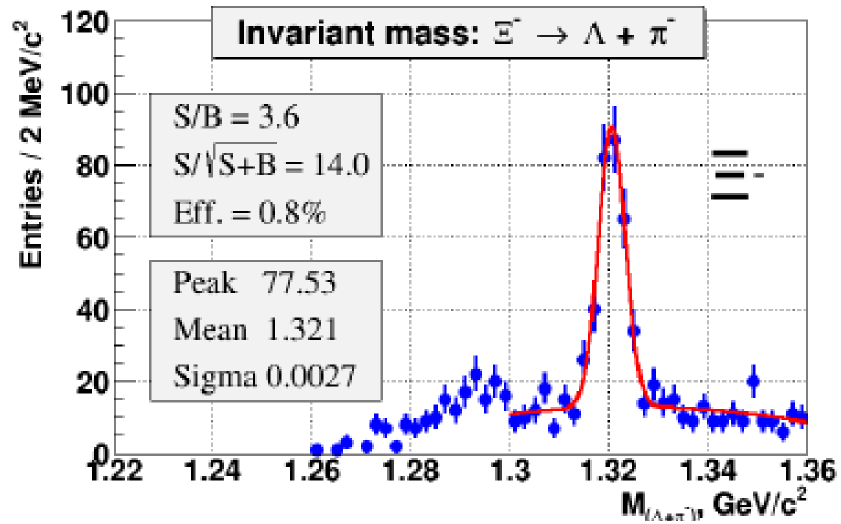




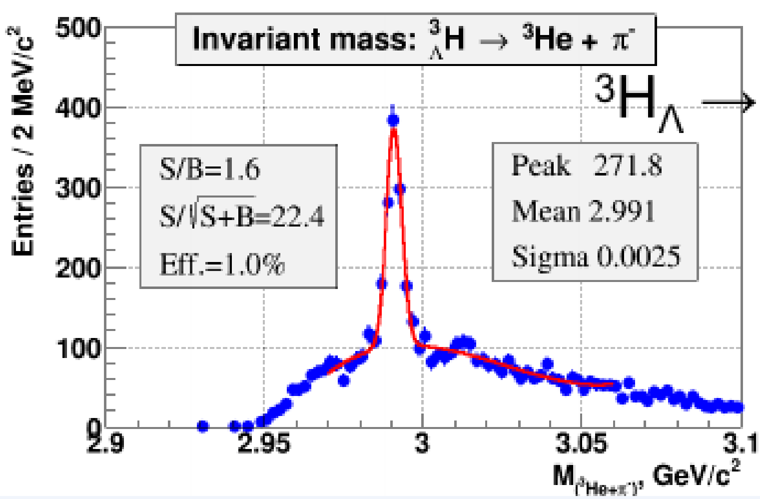
BmnRoot. Physics at BM@N



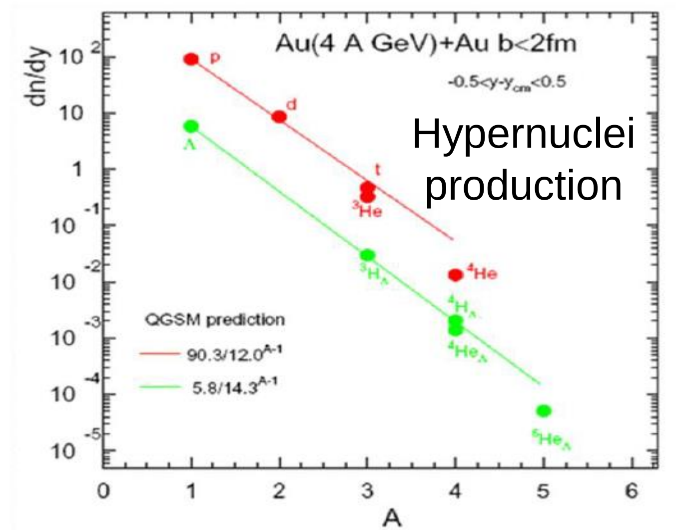
Au+Au, 4.5 AGeV, UrQMD, 900k central



Au+Au, 4.5 AGeV, 2M central events

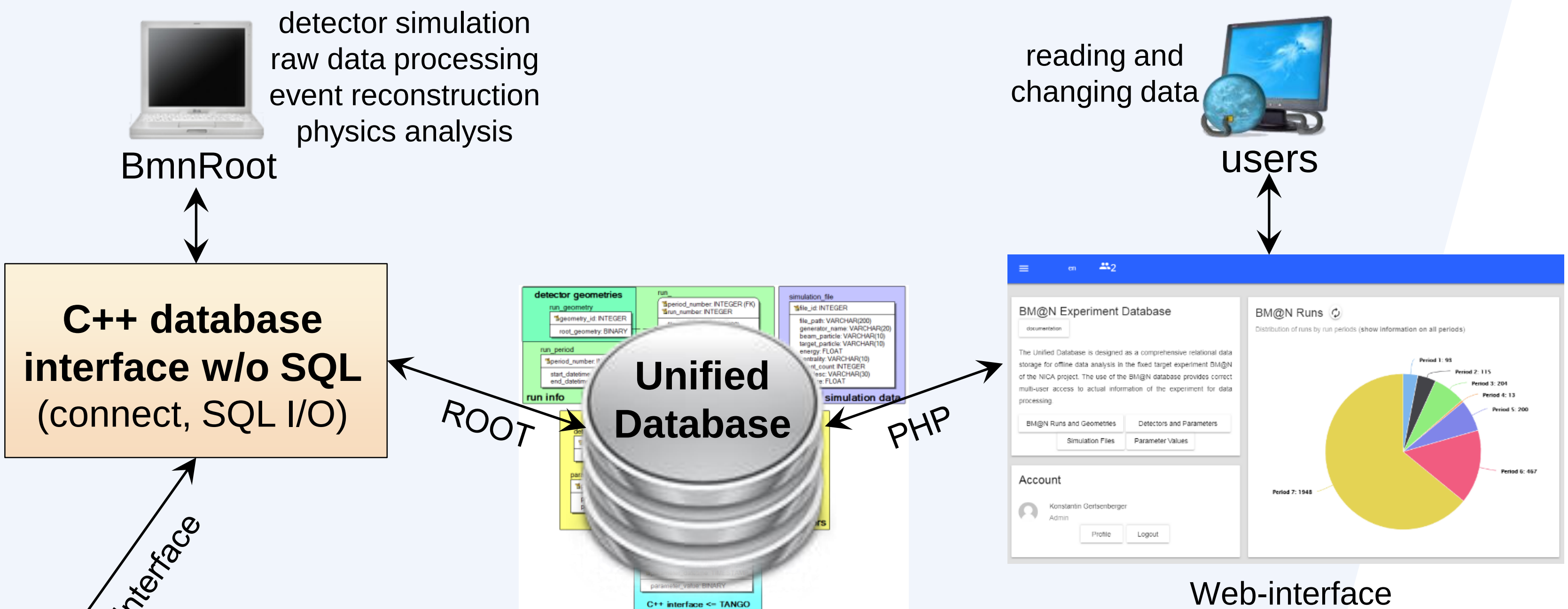


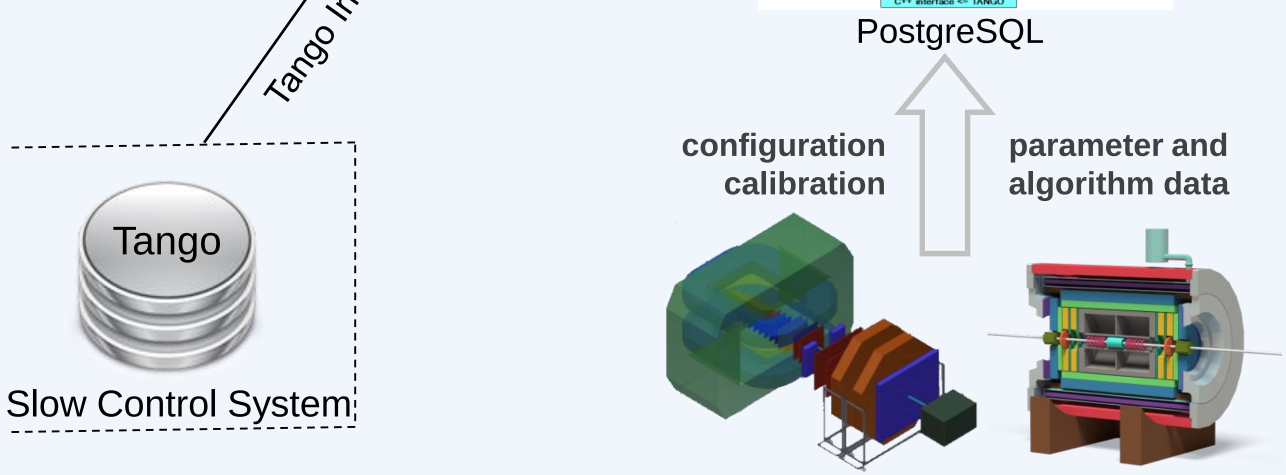
$^3H_\Lambda \rightarrow {}^3He\ \pi^-$



Hypernuclei production

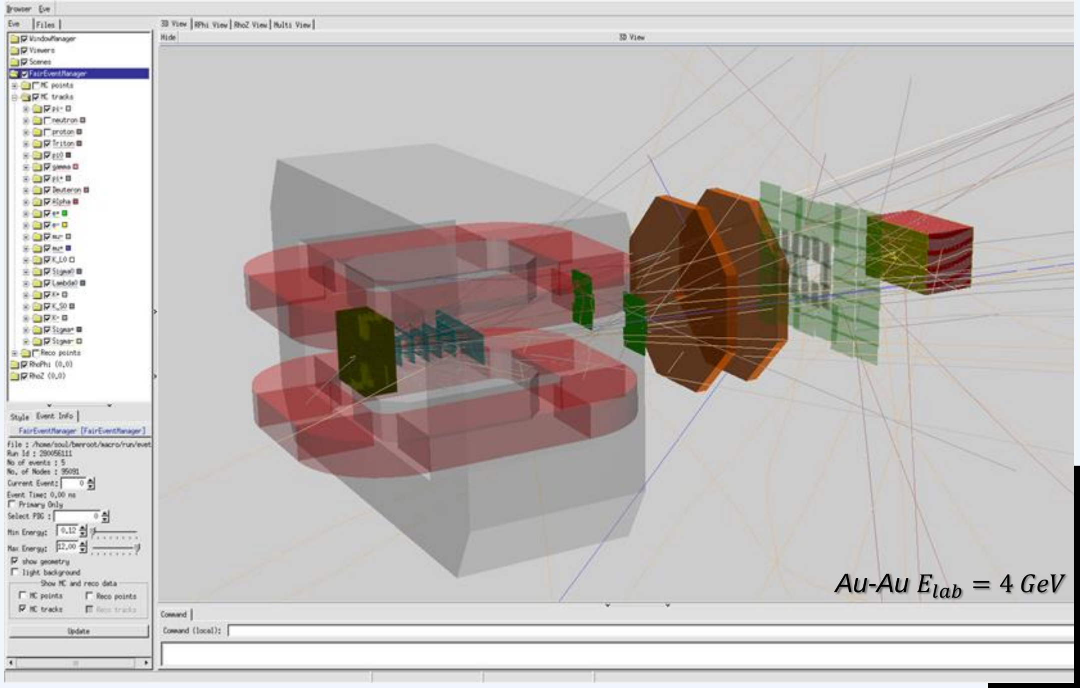
The Unified Database for offline processing





- central data storage for offline data analysis
- unified access and data management
- correct multi-user data processing
- ensuring the actuality, data consistency and integrity
- excluding the multiple duplication and use of outdated data
- automatic backup

Event Display for the NICA experiments



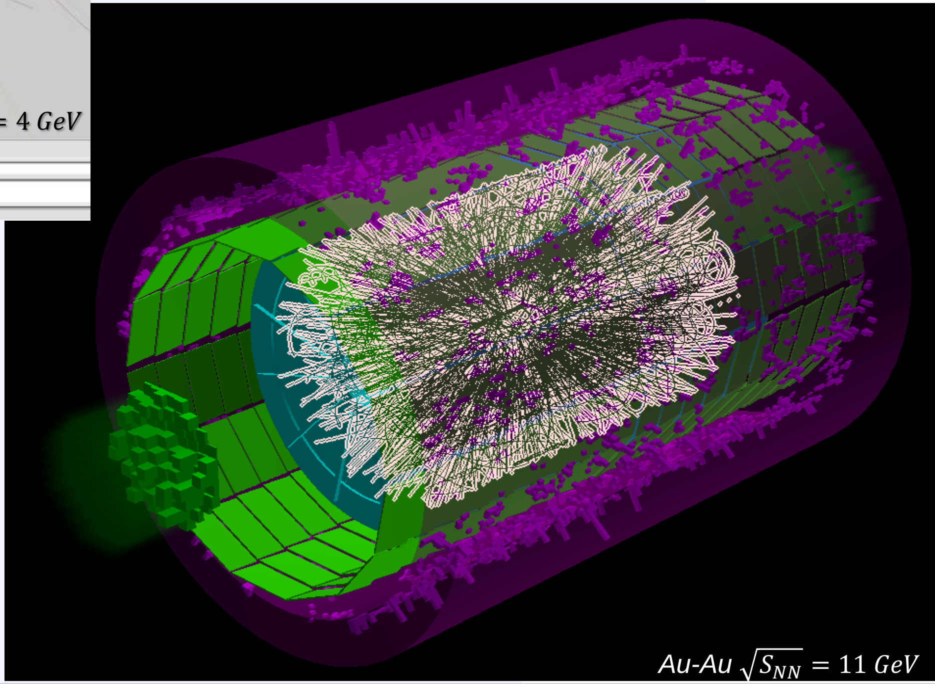
based on EVE package

Event Display for simulated event data:

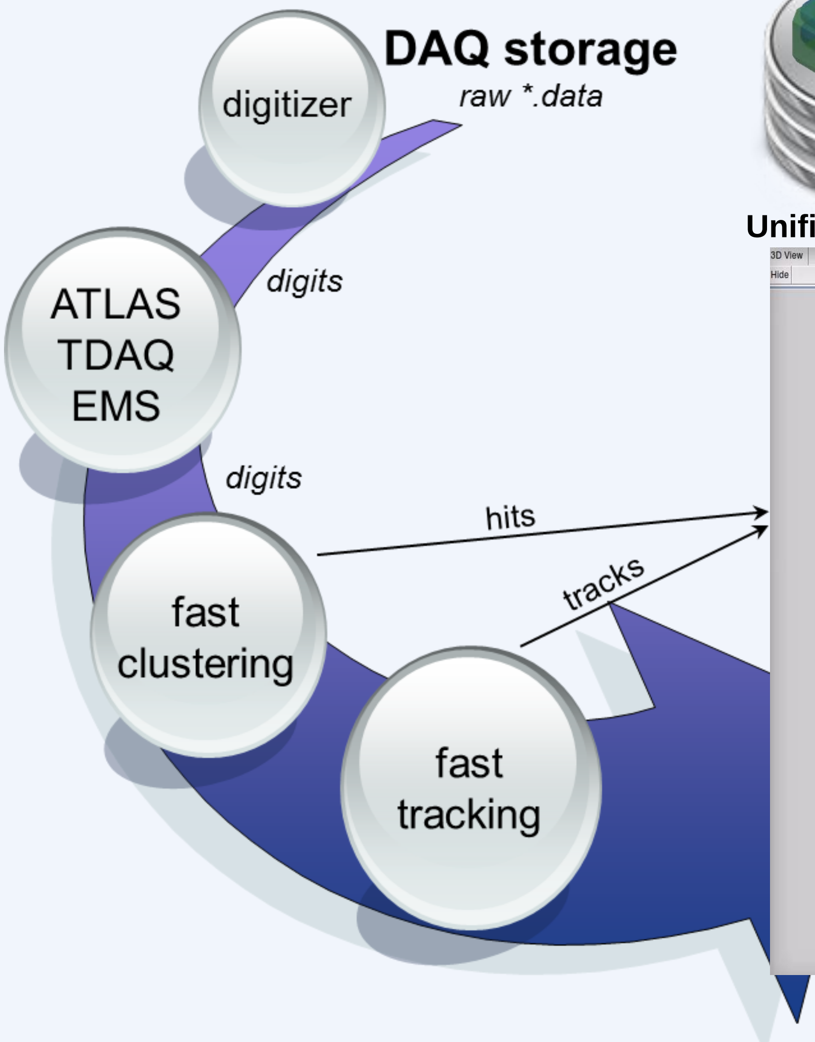
MC points, tracks, calorimeter towers

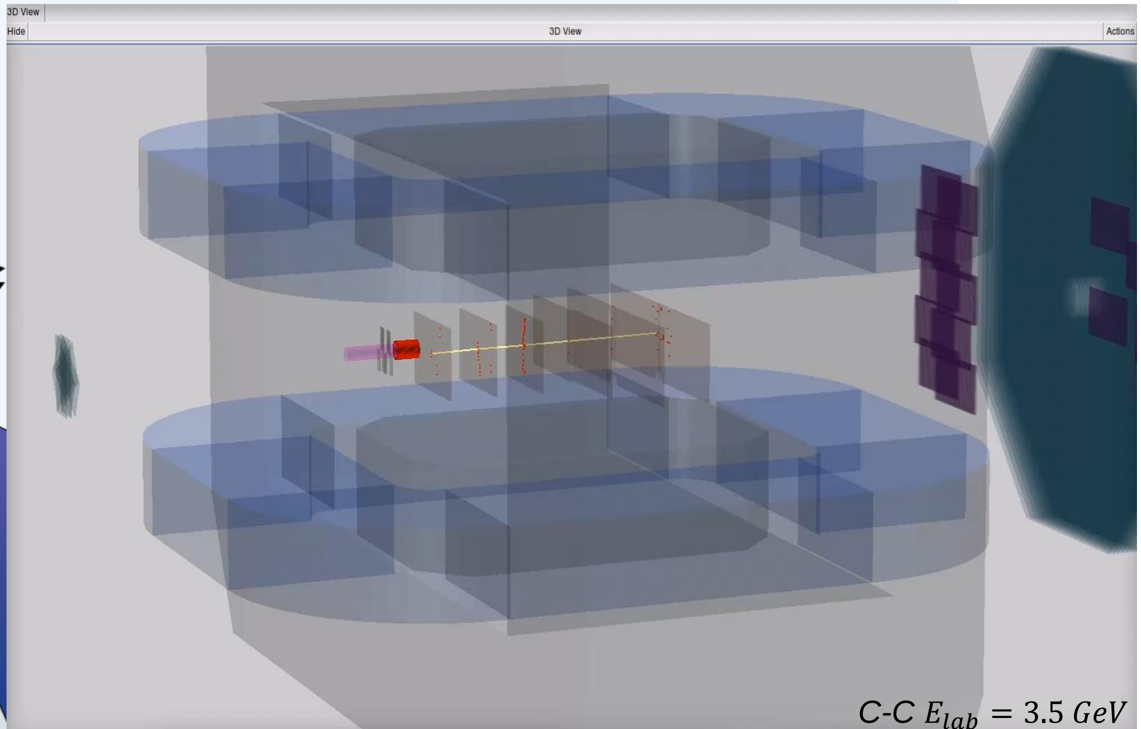
Event Display for reconstructed data:

hits, tracks, calorimeter towers



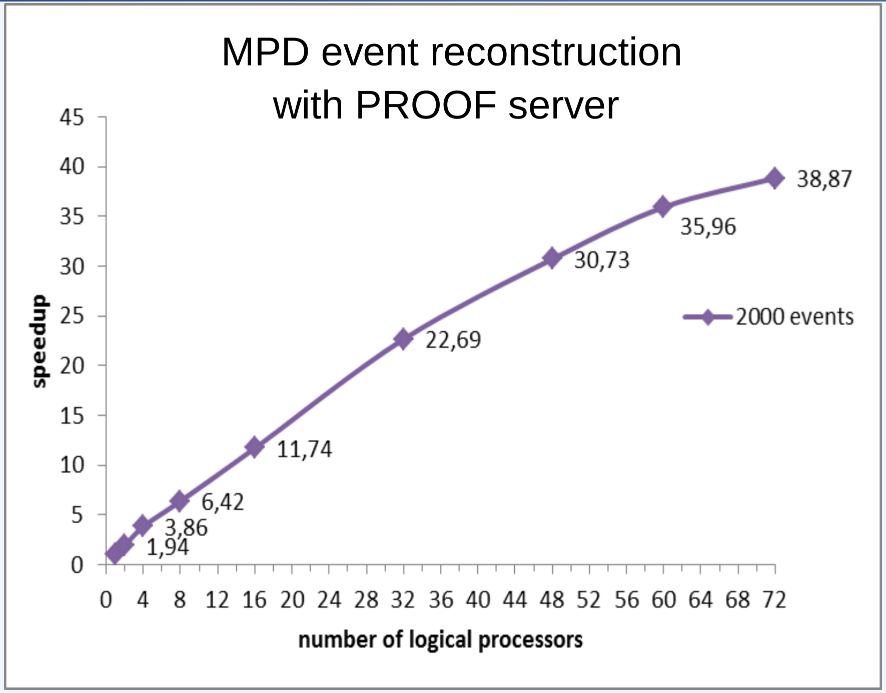
Online Event Display





Online Event Display
(GEM hits and tracks in run #1220)

Parallel event processing in MpdRoot&BmnRoot



PROOF (**P**arallel **ROO**T **F**acility) is a part of the ROOT software

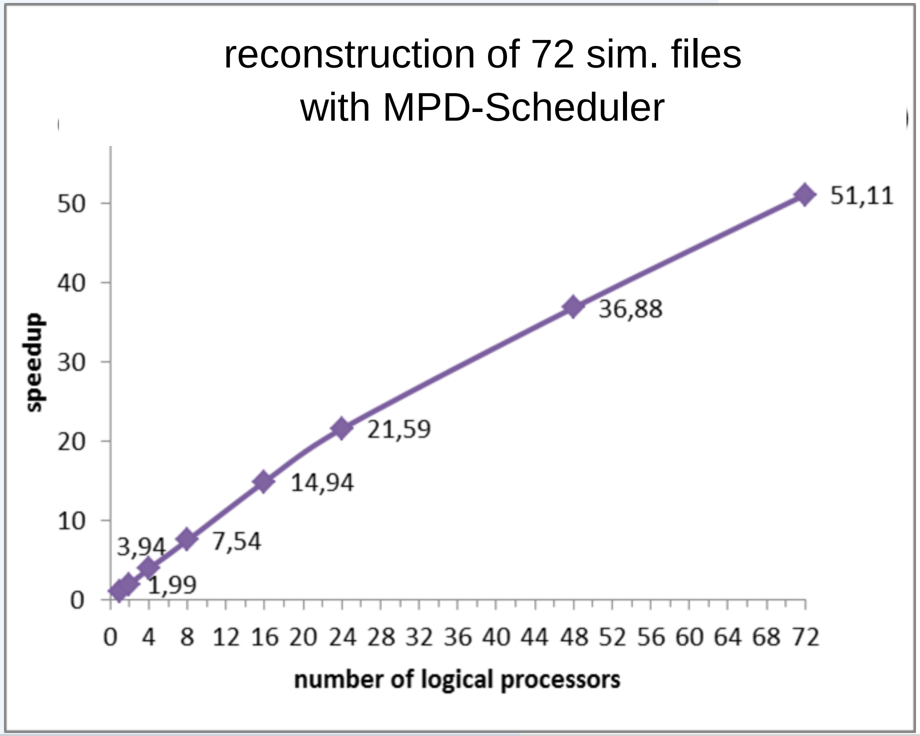
Parallel NICA event data processing in ROOT macros on the parallel architectures: user multicore machines, heterogeneous distributed clusters and GRID system

Scheduling system (MPD-Scheduler) for task distribution to parallelize NICA data processing on multicore machines and cluster nodes

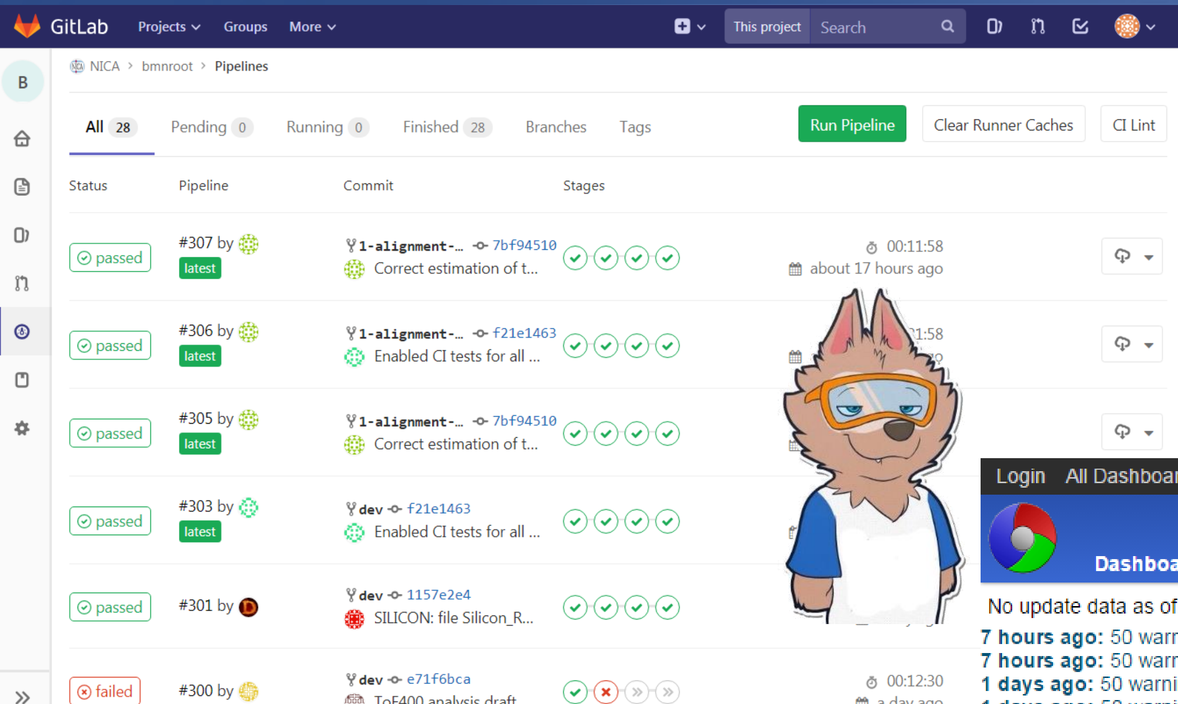
Supports SLURM, SGE and Torque system

Can use data of the Unified Database

Jobs are described and passed as XML file



Software Tests

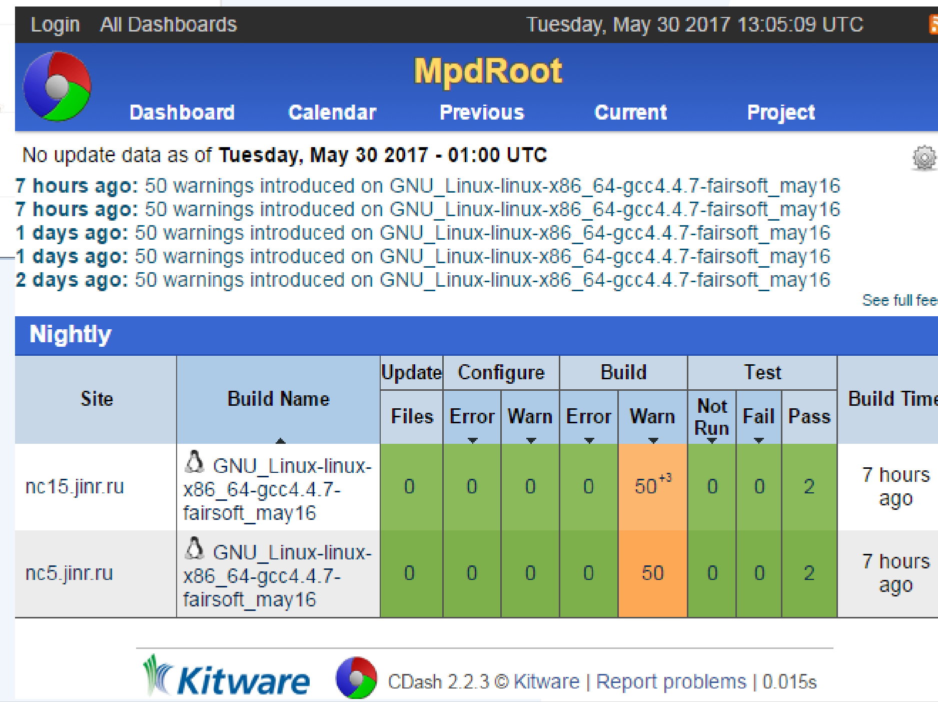


Nightly Tests

(CDASH + QA Histograms)

User Tests

by request in CDASH or GIT



GIT CI Tests on merge requests

check compilation and main macros

→ stable *dev* and *pro* branches

In case of compilation or macro errors

e-mail is sent to software developers

Summary

- The software frameworks for the NICA experiments provide to users all necessary tools to simulate any kind of detectors and study their properties.
- The user can describe geometry of the detector in details and visualize the geometry and detector response for the considered particles by event display.
- The methods of MPD and BM@N event reconstruction were implemented.
- Users are able to make the proposed physics analysis by the available MC generators for the NICA project to study feasibilities with these experiments.
- Many software systems have been developed: BM@N Unified Database, PROOF parallelization and MPD-Scheduler, Cluster Monitoring and Software Test System, Event Display and Online Histogramming, e-Logbook and official Web-site…
- The big work has been done, but a lot of packages should be added or improved for the experimental data taking and data processing in distributed systems:

online clustering and fast tracking, online alignment and calibrations, physics analyses methods, distributed and cloud computing for the NICA experiments…

Today, T3 - Hall 7, 15:00. prof. Vladimir V. Korenkov - The JINR distributed computing environment

Thank you for your attention!

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