Simulation and analysis framework for the NICA experiments

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- for MPD team

LIT JINR
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Nuclotron based Ion Collider Facility

- Fixed target experiments area (b.205)
- Extracted beams from Nuclotron
  - BM@N
- KRION-6T and HI-Lac (3.5 MeV/u)
- Nuclotron 0.6-4.5 GeV/u
- Booster (3-660 MeV/u) Inside Synchrophasotron Yoke
- Spin Physics Detector (SPD)
- Multi-Purpose Detector (MPD)
- NICA Collider (1-4.5 GeV/u, C ~ 500 m)
- HV e-cooler
Global sketch of HEP experiment

1. Determine Physics Goal
2. Decide subdetectors
   - Software simulation
3. Subdetector prototype
   - Electronics
4. System Integration
5. System Calibration
6. Data Taking
7. Data Analysis
8. Publish Results
The collision of two heavy nuclei which approach and smash against each other with almost the speed of light creates in the laboratory the primordial state of matter, called Quark-Gluon Plasma (QGP). The QGP expands like a fireball, cools and finally turns into ordinary matter.

“The very goal of the NICA facilities is the search for the mixed phase (MPD = “mixed phase detector”) of quark matter and baryon rich hadronic matter as a consequence of a first order phase transition, bearing strong analogies with a liquid-gas phase instability.”

NICA priorities
http://theor0.jinr.ru/twiki-cgi/view/NICA/WebHome
FairRoot universe

- **2004**: Start testing the VMC concept for CBM
- **2006**: Panda decided to join -> FairRoot: same Base package for different experiments
- **2010**: R3B joined
- **2011**: EIC (Electron Ion Collider BNL) EICRoot
- **2012**: SOFIA (Studies On Fission with Aladin)
- **2013**: SHIP - Search for Hidden Particles
- **2014**: First Release of CbmRoot
- **2014**: MPD (NICA) start also using FairRoot
- **2014**: ASYEOS joined (ASYEOSRoot)
- **2014**: GEM-TPC separated from PANDA branch (FOPIRoot)
- **2014**: CALIFA (CALorimeter for the In Flight detection of γ rays and light charged pArticles)
- **2014**: ENSAR-ROOT Collection of modules used by structural nuclear physics exp.
20 years of ROOT evolution
Simulation Framework for MPD&BM@N

- News
- Software
  - repositories
  - Software tests dashboard
- Forums
- Database for physics run
- Information etc.

- Inherits basic properties from FairRoot (developed at GSI), C++ classes
- Extended set of event generators for heavy ion collisions
- Detector composition and geometry; particle propagation by GEANT3/4
- Advanced detector response functions, realistic tracking and PID included
- Event display for Monte-Carlo and experimental data

Physics Models
- UrQMD
- Hybrid UrQMD
- LA QGSM
- SHIELD on fly
- HSD
- PHSD
- 3 Fluid Dynamics
- PLUTO

http://mpd.jinr.ru/
Multi-Purpose Detector general view
The FairRoot framework is fully based on the ROOT system. The user can create simulated data and/or perform analysis with the same framework. Moreover, Geant3 and Geant4 transport engines are supported, however the user code that creates simulated data do not depend on a particular monte carlo engine. The framework delivers base classes which enable the users to construct their detectors and/or analysis tasks in a simple way, it also delivers some general functionality like track visualization. Moreover an interface for reading magnetic field maps is also implemented.

**Posted By**: adminUser

**New FairSoft patch releases**

**Experiment Frameworks**

**R3BRoot** - Simulations and data analysis for R3B

**Recent content**

- New FairSoft patch releases
- Installing CbmRoot
- Installing the external packages

**OCT 04**
Included Packages

- cmake 3.3.2 (only installed if installed version is too old)
- gtest 1.7.0
- gsl 1.16
- boost 1_59_0
- Pythia6 416
- HepMC 2.06.09
- Pythia8 212
- Geant4 10.01.p2
- xrootd 4.1.1
- ROOT v5.34.34 or v6.04.02
- Pluto v5.37
- Geant321+_vmc v2-0
- VGM v4-3
- G4VMC v3-2
- MillePede V04-03-01
- ZeroMQ 4.1.3
- Protocol Buffers 2.6.1
- Nano Message 0.6-beta

In case the python bindings are build the following additional packages will be installed

- XercesC 3.1.2
- G4Py Version which comes with Geant4
OS dependences

Build Prerequisites

Before installing FairRoot many other packages are necessary. Some of them can be installed using the package manager of the used Linux distribution, but many others have to be installed from sources. This is necessary because many of these programs can’t be installed using the package manager or FairSoft need the programs compiled with special settings.

To make the installation procedure as easy as possible we provide an additional package called FairSoft (sometimes also called “external packages”) which takes care of the installation of all needed programs in the right order and with the right compilation flags. In the end all additional software is installed in one directory.

The FairSoft package contains a configuration script which checks if all the needed system packages are installed. If some of the system packages are missing the configuration script will stop with a detailed error message. The complete list of needed system packages can be found in the DEPENDENCIES file. This file contain also complete command lines to install the needed packages on the most common Linux systems.

The only prerequisite for the FairSoft installation on Linux or Mac OS X systems is CMake which has either to be installed using the package manager or from sources which can be downloaded from here.

The instructions how to install FairSoft can be found here.
Detector simulation

- 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

GEANT

Experiments framework
Multi Purpose Detector

Stage 1
TPC, TOF, ECAL, ZDC, FFD

Stage 2
Stage 1 +
ITS, ETOF, EEMC, ECT, CPC
MPD subdetectors

TPC with Straw tube tracker

Straw tube tracker
MPD subdetectors

TPC (Time Projection Chamber)
XY slice

- field cage pin
- outer field cage
- central electrode (membrane)
- outer wall
- inner wall
- inner tube flange
- inner field cage
- aluminium frame
- readout chamber (pad plane + al.body)
- PCB
- outer endcap (aluminium)
- inner endcap (aluminium)

Material budget, TPC (XY)

TPC detailed view
Radiation thickness
Reconstruction chain

- 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
- Physics analysis
Clustering in TPC
MPD magnetic field

- Transition from a constant magnetic field to the real field map.
- Interpolation of the field between the map nodes using
  \[ L(r, z) = \sum_{i=1}^{5} \sum_{j=1}^{5} a_{ij} r^i z^j \]
Tracking
MPD acceptance
Charged particle ID in TPC & TOF

TPC
PID: Ionization loss (dE/dx) 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

Parameterization:
3G + bkg. exponents
MPD Event Display
Particle reconstruction in TPC

GeoTracks

MC points

Hits

reconstructed tracks
Event display for reconstructed tracks

New physics with the MC generators

Direct flow slope changes

NICA energy scan

Net baryon rapidity curvature
Barionic Matter @ Nuclotron
Monte-Carlo tracks

AuAu $E_{\text{lab}} = 4.\text{GeV}$
GEM hits reconstruction

✔ Realistic hitfinder in GEM plane
✔ Fake hits production is implemented
Reconstructed tracks
Transition from a constant magnetic field to the real field map.
- Interpolation of the field between the map nodes.
- Extrapolation of the field map to out-of-magnet region.

\[
B_{comp}(x, y, z) = C(x, y) \cdot e^{-\frac{(z - \mu(x, y))^2}{2\sigma(x, y)^2}}
\]

\[
\lim_{z \to \infty} B_{comp}(x, y, z) = 0
\]
Tracking in GEM

L1 (CBM) tracking Implementation for GEM

Coordinates transformation With LIT kalman filter

G.Ososkov presentation
GEM tracker properties

Phase space / acceptance to primary protons:

Momentum resolution / detection efficiency

\[ \Delta p / p \text{ vs } p: 12 \text{ stations, } B = 0.44 \]

"Reconstructable" primaries: \( B = 0.44 \)
Physics at BM@N

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

Invariant mass: $\Lambda^0 \rightarrow p\pi^-$

- $S/B = 3.9$
- $S/\sqrt{S+B} = 83.5$
- Eff. = 8.9%
- Peak 3221.9
- Mean 1.115
- Sigma 0.0023

Au+Au, 4.5 AGeV, 2M central events

Invariant mass: $^3\Lambda H \rightarrow ^3\text{He} + \pi^-$

- $S/B = 1.6$
- $S/\sqrt{S+B} = 22.4$
- Eff. = 1.0%
- Peak 271.8
- Mean 2.991
- Sigma 0.0025
Data... Data... Database

C++ database interface
(connect, SQL I/O)

central database

Tango

slow control system

BMNRoot

raw data processing
event reconstruction
physical analysis

Web interface

users

reading and changing data

Postgres, SQL
automatic backup

existing configuration,
calibration, parameter
and algorithm data
(HTML, Excel, TXT)

gameometry
database

raw data processing
event reconstruction
physical analysis

DoTangoData class

Tango

slow control system

Web interface

users

reading and changing data

Postgres, SQL
automatic backup

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(HTML, Excel, TXT)

gameometry
database
NICA distributed computing

LHEP
NICA cluster

WUT
Poland

Sosny
Belarus

LIT
MONTE CARLO GENERATORS for NICA/FAIR physics

- Ultrarelativistic Quantum Molecular Dynamics (UrQMD)
- Quark Gluon String Model
- Shield
- Parton Hadron String Dynamics
- Hybrid UrQMD
- EPOS
- vHLLE UrQMD
- 3 Fluid Dynamics model

Nuclear fragments

Femtoscopy

Flows

baryon stopping power
Thank you for attention

More information: nica.jinr.ru
mpd.jinr.ru
Radii versus kT with vHLLE+UrQMD model for ππ at 7.7 ; 11.5 GeV
Source Function with vHLLE + UrQMD model for ππ at 7.7 ; 11.5 GeV
UrQMD 3.4 model

Source Function with UrQMD 3.4 model for $\pi\pi$ at 5; 7; 9; 11 GeV
Baryon stopping power

\[
\frac{dN}{dy} = a \left( \exp \left\{ -\left( \frac{1}{w_s} \right) \cosh(y - y_s) \right\} \\
+ \exp \left\{ -\left( \frac{1}{w_s} \right) \cosh(y + y_s) \right\} \right)
\]
3FD Model: Baryon stopping power

\[ C_y = \left( y_{\text{beam}}^3 \frac{d^2N}{dy^2} \right)_{y=0} \left( y_{\text{beam}} \frac{dN}{dy} \right)_{y=0} = \left( y_{\text{beam}} / w_s \right)^2 \left( \sinh^2 y_s - w_s \cosh y_s \right) \]

Yu.B. Ivanov, PL B721 (2013) 123
arXiv:1211.2579

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Contents

1) NICA priorities
2) General aspects
3) Phases of QCD matter at high baryon density
4) Hydrodynamics and hadronic observables
5) Femtoscopy, correlations and fluctuations
6) Mechanisms of multi-particle production
7) Electromagnetic probes and chiral symmetry in dense QCD matter
8) Local P and CP violation in hot QCD matter
9) Cumulative processes
10) Polarization effects and spin physics
11) Related topics
12) Fixed Target Experiments
13) Hypernuclei Production in Heavy Ion collisions
Observables

I stage: mid rapidity region (good performance)

- Particle yields and spectra ($\pi, K, p, \text{clusters, } \Lambda, \Xi, \Omega$)
- Event-by-event fluctuations
- Femtoscopy involving $\pi, K, p, \Lambda$
- Collective flow for identified hadron species
- Electromagnetic probes (electrons, gammas)

II stage: extended rapidity + ITS

- Total particle multiplicities
- Asymmetries study (better reaction plane determination)
- Di-Lepton precise study (Endcap Calorimeter)
- Charm
- Exotics (soft photons, hypernuclei)

Measurements regarded as complementary to RHIC/BES and CERN/NA61,
However, higher statistics & (close to) the total yields for rare probes at MPD
No boost invariance at NICA – more accurate source parameters fit without rapidity cut
Rapidity dependence of the fireball thermal parameters will be possible at NICA
NICA physics

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