Multi-Purpose Detector

V. Kireyeu[1]

[1]VBLHEP, JINR

July 2, 2021

Chapter I

Introduction

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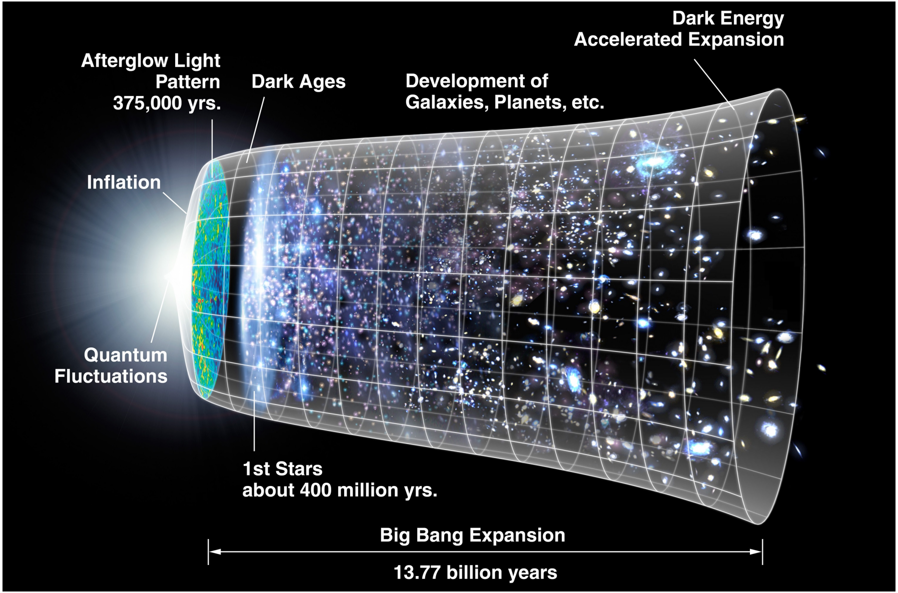
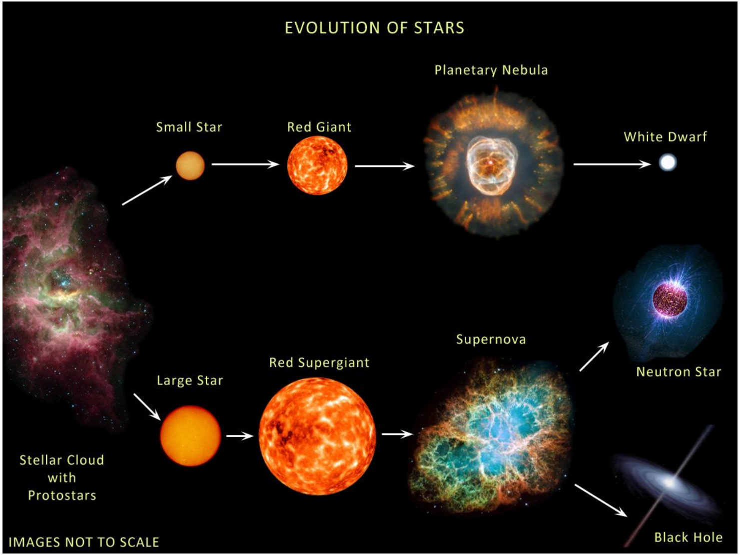
Introduction

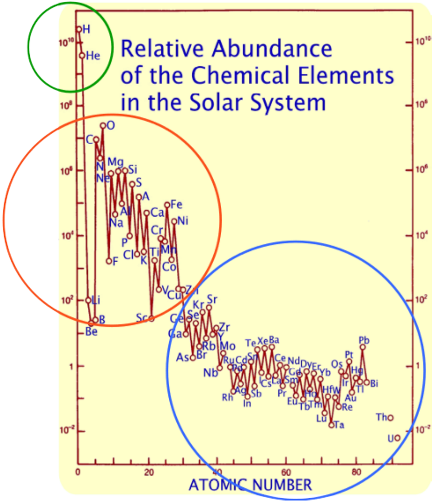


Introduction: evolution of stars



Courtesy of Anna Watts

Introduction: the origin of elements

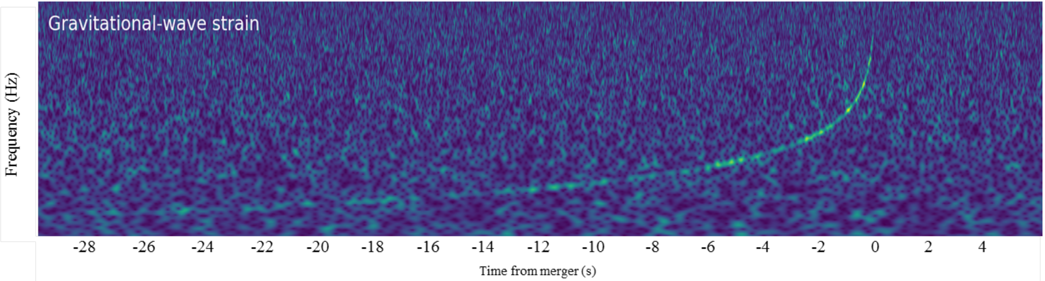


Nucleosynthesis after the Big Bang

Nuclear fusion in stars

Neutron capture in Red Giants (s-process) or in supernovae or neutron star mergers (r-process)

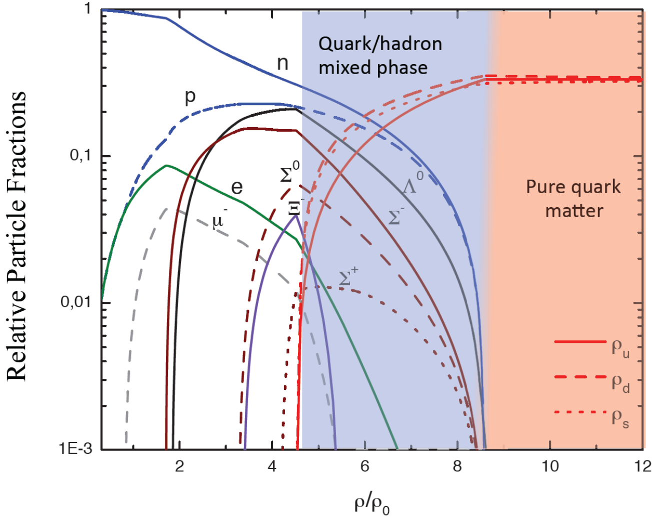
Introduction: neutron star merger



Omega Scan of LIGO's First Neutron Star Merger Detection

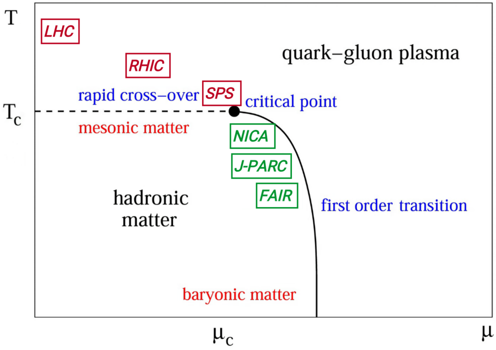
Gravitational wave detection from GW170817, August 17, 2017, LIGO-Virgo Collaborations

Introduction: quark matter in massive neutron stars?



M. Orsaria, H. Rodrigues, F. Weber, G.A. Contrera, Phys. Rev. C 89, 015806, 2014

Introduction: phase diagram of strongly interacting matter



Turko, L., Particles 2018, 1, 296-304

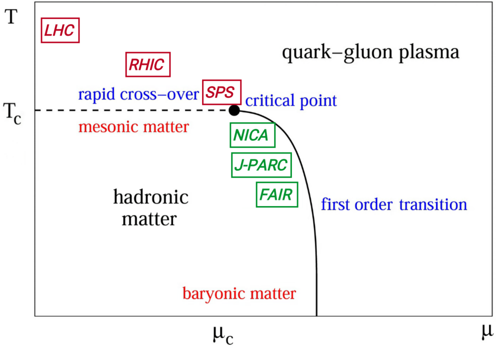
Early Universe:

- Large Hadron Collider (LHC)
- Relativistic Heavy Ion Collider (RHIC)

Neutron star mergers:

- Super Proton Synchrotron (SPS)
- Nuclotron based Ion Collider fAcility (NICA)
- Facility for Antiproton and Ion Research (FAIR)

Introduction: phase diagram of strongly interacting matter

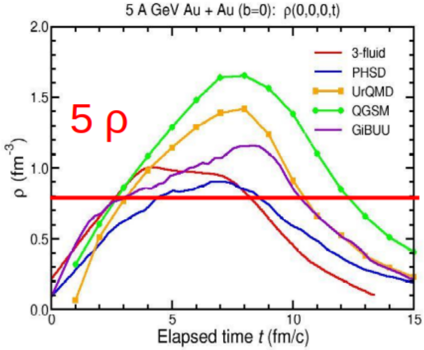


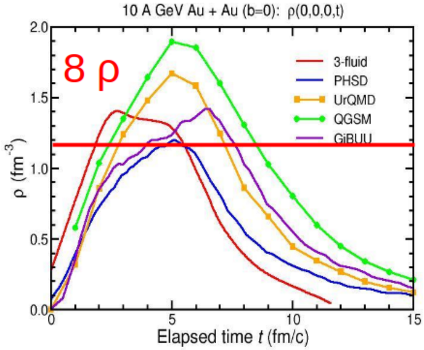
Turko, L., Particles 2018, 1, 296-304

Heavy-Ion Collisions (HIC):

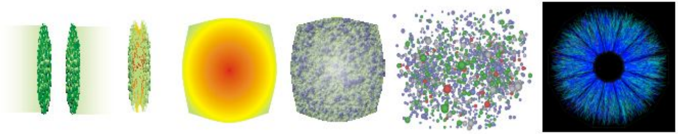
- Search for the critical point
- Study of the phase transition from hadronic to partonic matter – Quark-Gluon-Plasma
- Search for the signatures of chiral symmetry restoration
- Study of the in-medium properties of hadrons at high baryon density and temperature

Introduction: baryon densities in central HIC

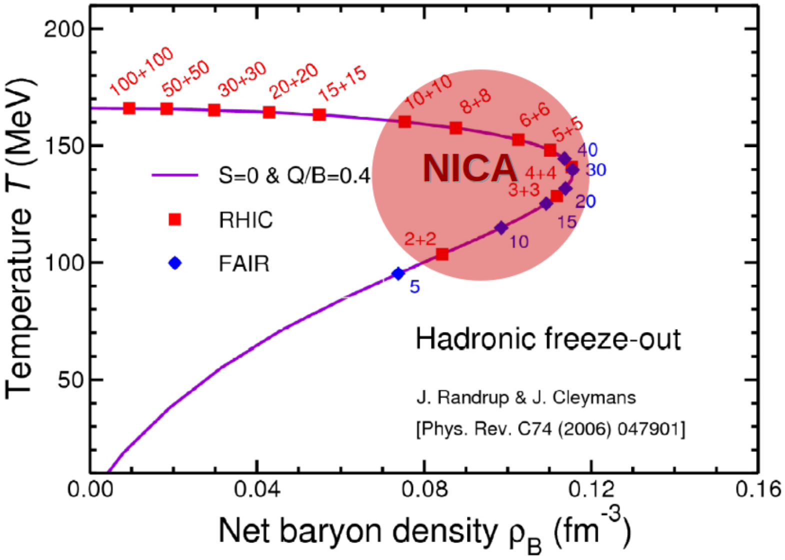




Courtesy of J. Randrup

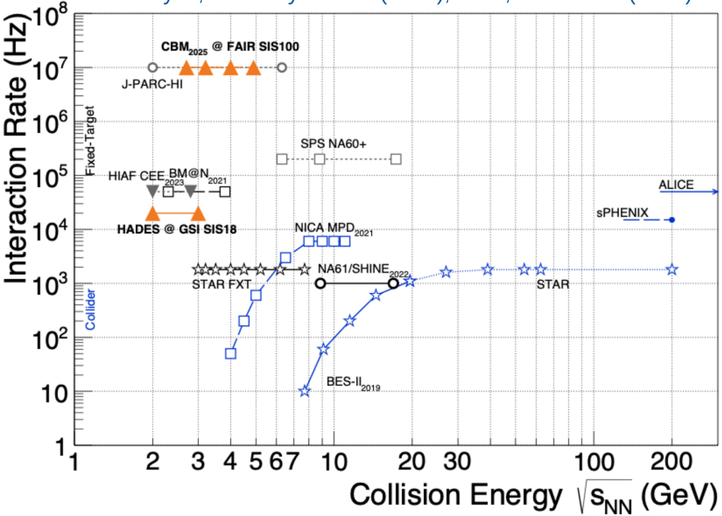


Introduction: the "freeze-out" condition



Introduction: where we are?

T. Galatyuk, Nucl.Phys. A982 (2019); CBM, EPJA 53 3 (2017) 60



Chapter II

Observables

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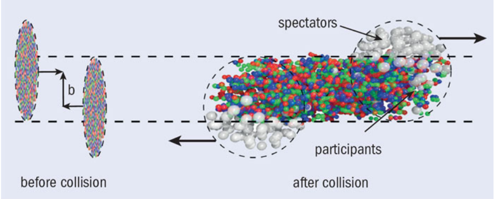
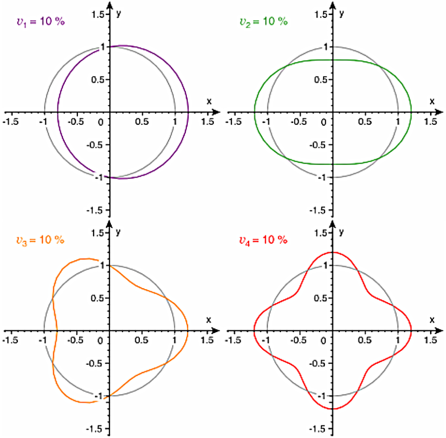
Observables: Flow



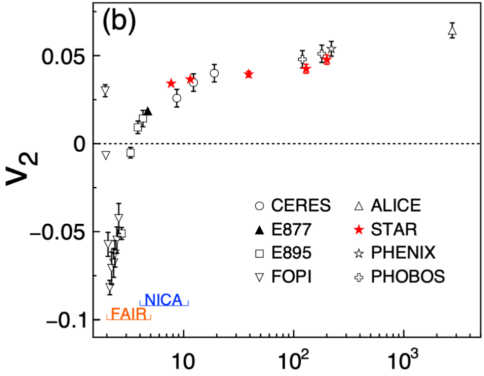
Initial eccentricity ϵ_n leads to momentum anisotropy v_n

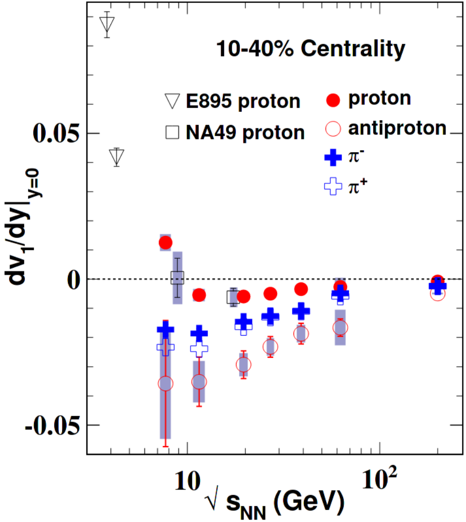
$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left(1+\sum_{n=1}^{\infty}2v_n cos[n(\phi-\Psi_n)]\right)$$

$$v_n = \langle cos[n(\phi-\Psi_n)]\rangle, \phi = atan\frac{p_y}{p_x}$$

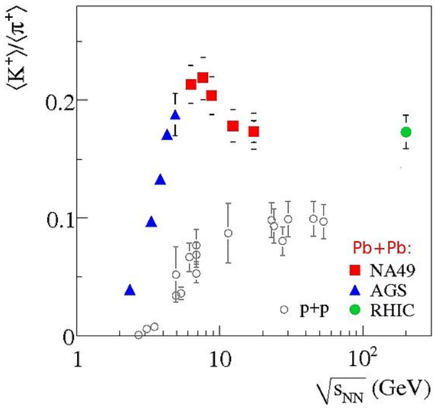


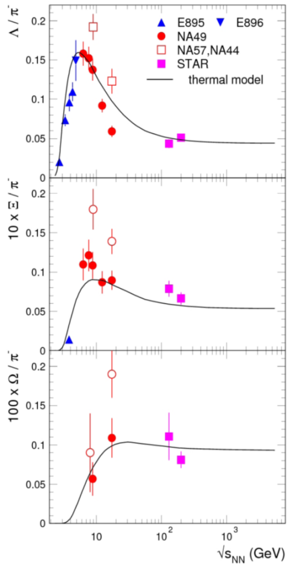
Observables: Flow





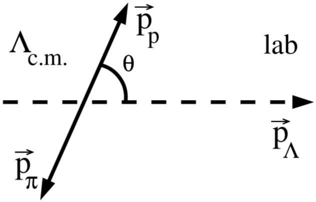
Observables: Strangeness





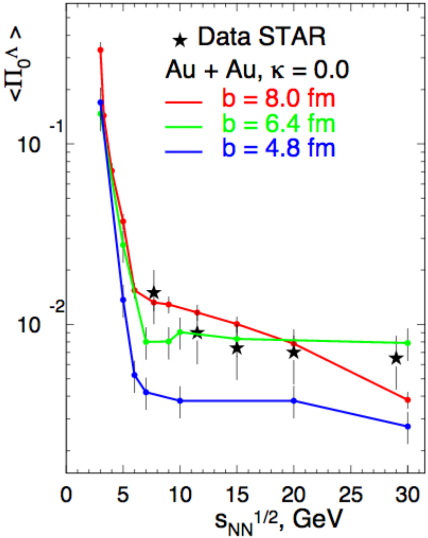
NA49 : Phys. Rev. C 77, (2008)

Observables: Λ polarization



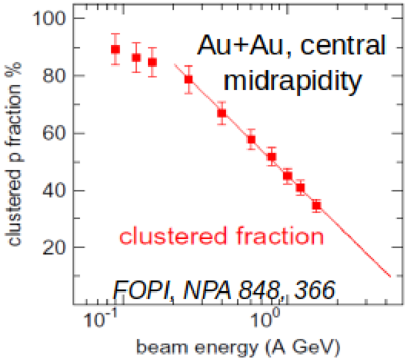
$$\Lambda^0 \longrightarrow p + \pi^-$$
$$P_\Lambda = \frac{1}{\alpha}\frac{\langle cos(\theta_{cm})\rangle}{\langle cos^2(\theta_{cm})\rangle}$$

θ = angle between proton momentum and Λ polarization plane in Λ rest frame.
$\alpha = 0.732$ – Λ^0 decay assymetry parameter

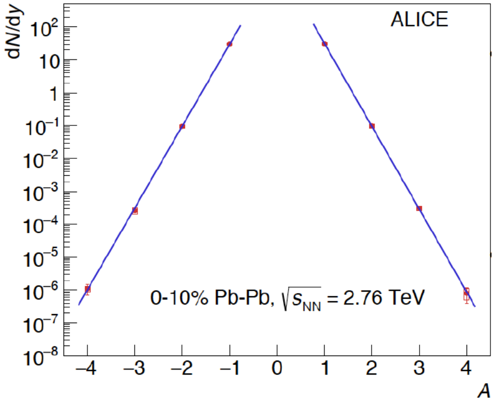


arxiv: 1701.06657

Observables: "ice in fire"

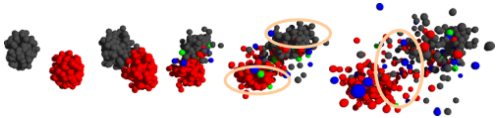


Low energy: up to 20% of protons in central collisions are bound into the clusters.



High energy HIC – "Ice in a fire" puzzle: how the weakly bound objects can be formed in a hot environment?

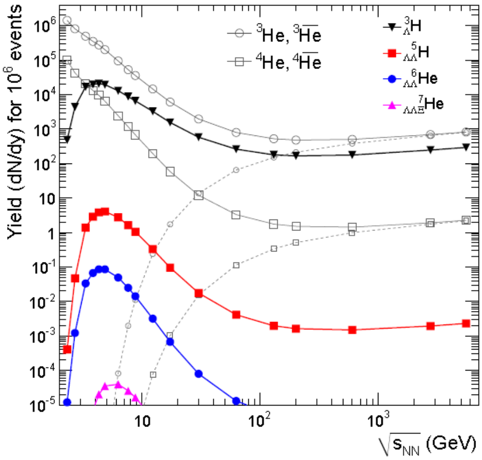
Observables: Hypernuclei



IQMD: Ch. Hartnack

(Anti-)hypernuclei production:

- at mid-rapidity by Λ coalescence during expansion
- at projectile/target rapidity by re-scattering/absorption of Λ by spectators



A. Andronic et al., Phys. Lett. B697 (2011) 203

Chapter III

Multi-Purpose Detector (MPD)

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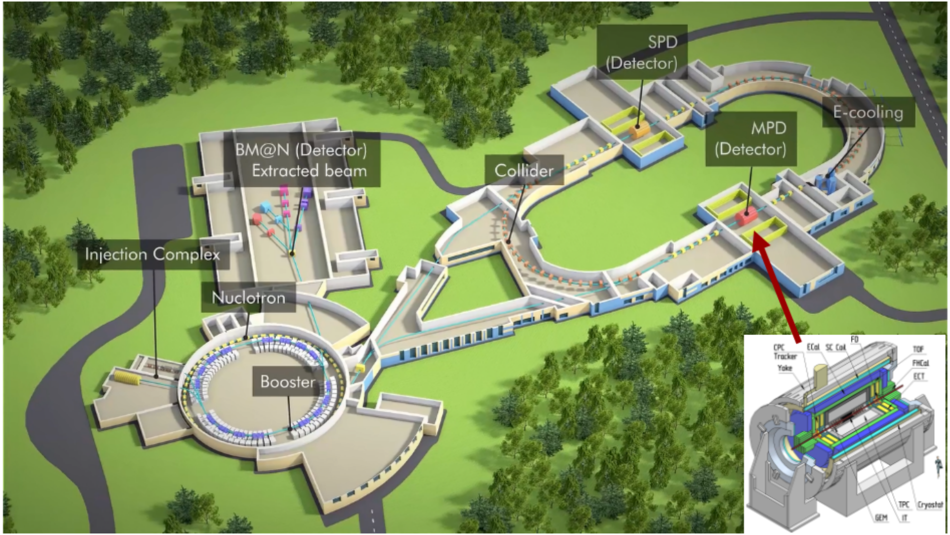
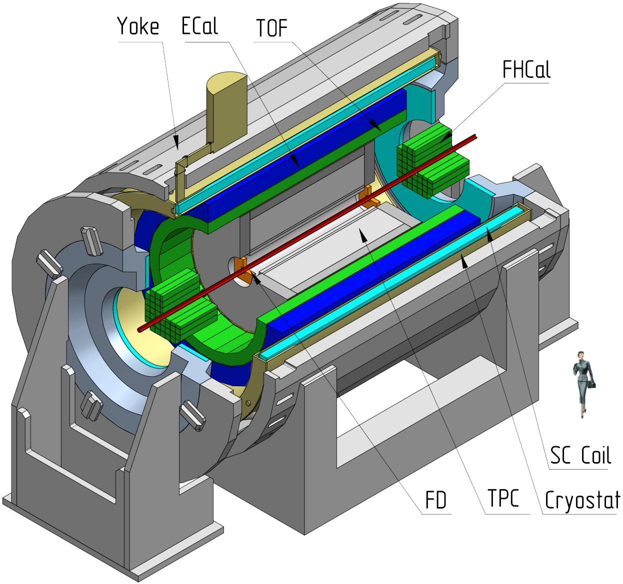
NICA basic facility



MPD: general view



Main target:

study of hot and dense baryonic matter at the energy range of max net baryonic density

MPD: Collaboration

12 Countries, more than 500 participants, 42 Institutes and JINR

- AANL, Yerevan, Armenia
- Baku State University, NNRC, Azerbaijan
- University of Plovdiv, Bulgaria
- University Tecnica Federico Santa Maria, Valparaiso, Chile
- Tsinghua University, Beijing, China
- USTC, Hefei, China
- Huzhou University, Huizhou, China
- Central China Normal University, China
- Fudan University, Shanghai, China
- Shandong University, Shandong, China
- IHEP, Beijing, China
- University of South China, China
- Three Gorges University, China
- Institute of Modern Physics, CAS, Lanzhou, China
- Palacky University, Olomouc, Czech Republic
- NPI CAS, Rez, Czech Republic
- Tbilisi State University, Tbilisi, Georgia
- **Joint Institute for Nuclear Research**
- FCFM-BUAP Puebla, Mexico
- FC-University of Colima, Colima, Mexico
- FCFM-UAS, Culiacán, Mexico
- ICN-UNAM, Mexico City, Mexico
- CINVESTAV, Mexico City, Mexico
- Universidad Autónoma Metropolitana, Iztapalpa, Mexico
- Institute of Applied Physics, Chisinev, Moldova
- WUT, Warsaw, Poland
- NCNR, Otwock – Świerk, Poland
- University of Wrocław, Poland
- University of Silesia, Poland
- University of Warsaw, Poland
- Jan Kochanowski University, Kielce, Poland
- Institute of Nuclear Physics, PAS, Cracow, Poland
- Belgorod National Research University, Russia
- INR RAS, Moscow, Russia
- NRNU MEPhI, Moscow, Russia
- Moscow Institute of Science and Technology, Russia
- North Osetian State University, Russia
- NRC Kurchatov Institute, ITEP, Russia
- Kurchatov Institute, Moscow, Russia
- St. Petersburg State University, Russia
- SINP, Moscow, Russia
- PNPI, Gatchina, Russia
- Vinča Institute of Nuclear Sciences, Belgrade, Serbia

Still growing, open for new member institutions!

MPD: physics program

Global observables
G. Feofilov, A. Ivashkin

- Total event multiplicity
- Total event energy
- Centrality determination
- Total cross-section measurement
- Event plane measurement at all rapidities
- Spectator measurement

Spectra of light flavor and hypernuclei
V. Kolesnikov, Xianglei Zhu

- Light flavor spectra
- Hyperons and hypernuclei
- Total particle yields and yield ratios
- Kinematic and chemical properties of the event
- Mapping QCD Phase Diagram

Correlations and Fluctuations
K. Mikhailov, A. Taranenko

- Collective flow for hadrons
- Vorticity, Λ polarization
- E-by-E fluctuation of multiplicity, momentum and conserved quantities
- Femtoscopy
- Forward-Backward correlations
- Jet-like correlations

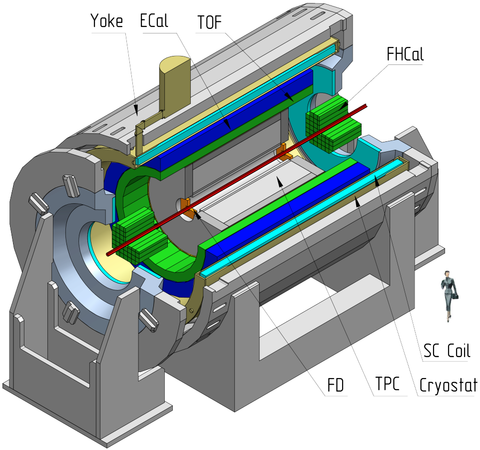
Electromagnetic probes
V. Riabov, Chi Yang

- Electromagnetic calorimeter meas.
- Photons in ECAL and central barrel
- Low mass dilepton spectra in-medium modification of resonances and intermediate mass region

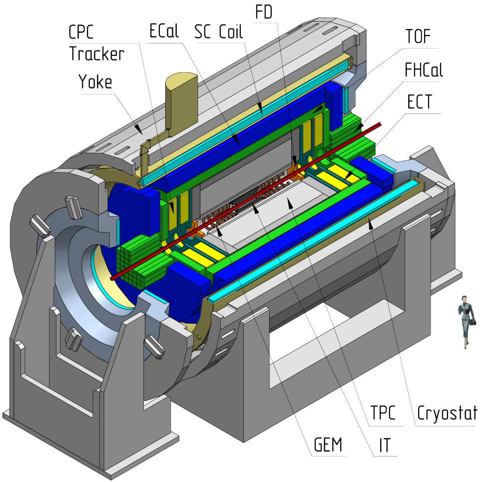
Heavy flavor
Wangmei Zha, A. Zinchenko

- Study of open charm production
- Charmonium with ECAL and central barrel
- Charmed meson through secondary vertices in ITS and HF electrons
- Explore production at charm threshold

MPD: 2 stages

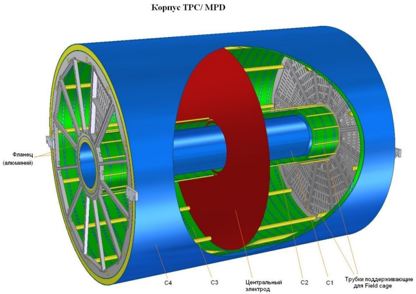


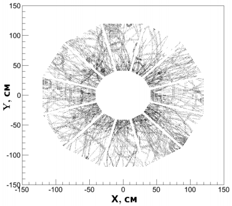
Stage I



Stage II

MPD: Time Projection Chamber (TPC)

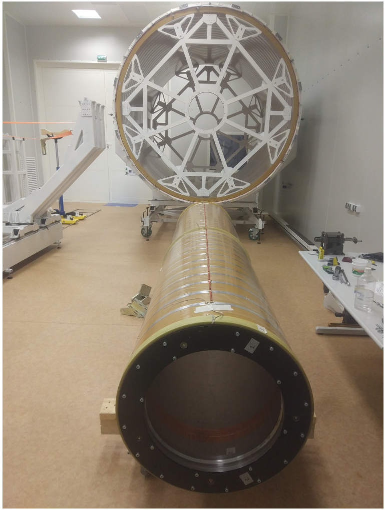




The main tracking detector

- The overall acceptance of $|\eta| < 1.2$
- The momentum resolution for charge particles under 3% in $0.1 < p_T < 1$ GeV/c.
- Two-track resolution of about 1 cm.
- Hadron and lepton identification by dE/dx measurements with a resolution better than 8%.

MPD: Time Projection Chamber (TPC)



The main tracking detector

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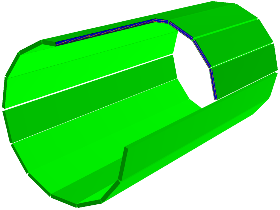
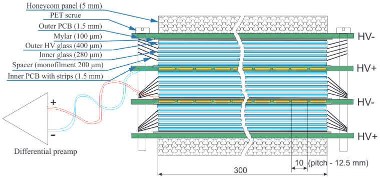
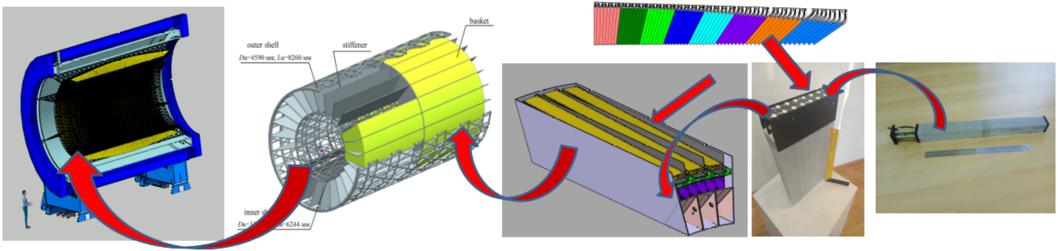
MPD: Time of Flight system (ToF)





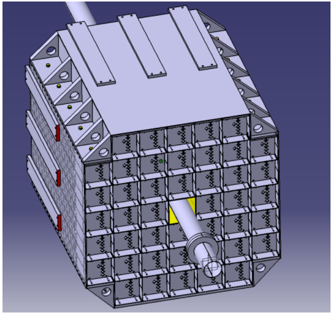
- Identification of charged hadrons (PID) at intermediate momenta (0.1 – 2 GeV/c).
- Based on Multigap Resistive Plate Chambers
- Maximum occupancy does not exceed 15% per channel.
- Geometrical efficiency ≈ 95%.
- Time resolution of MRPC prototype ≈ 60 ps.

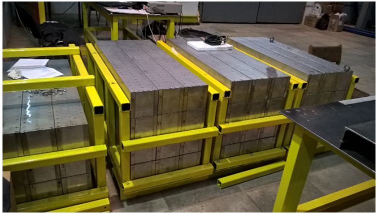
MPD: Electromagnetic Calorimeter (ECAL)



- Measurements for electromagnetic and hadronic showers caused by particle interaction.
- Modules are Pb+Sc "Shashlyk" type alternating, light is carried by Wave Length Shifting Fibers to MAPD photon counters.
- Trapezoidal projective geometry.

MPD: Forward Hadron Calorimeter (FHCal)

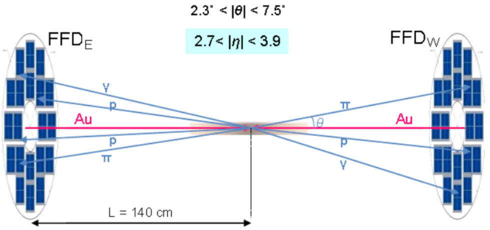




- Measures the energy of non-interacting nucleons and fragments (spectators) in AA collisions.
- Determination of reaction plane and centrality
  - the reaction plane with the accuracy $\approx 20^0 - 30^0$
  - the centrality with accuracy below 10%
- FHCal coverage: $2.2 < |\eta| < 4.8$

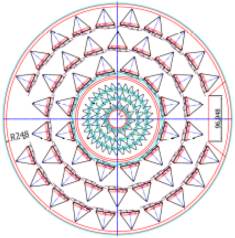
MPD: Fast Forward Detector, Inner Tracking System

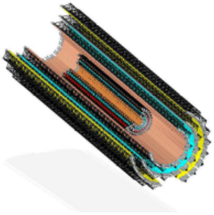
Fast Forward Detector (FFD)



- Fast and effective triggering of collisions
- Generation of the start pulse for the TOF

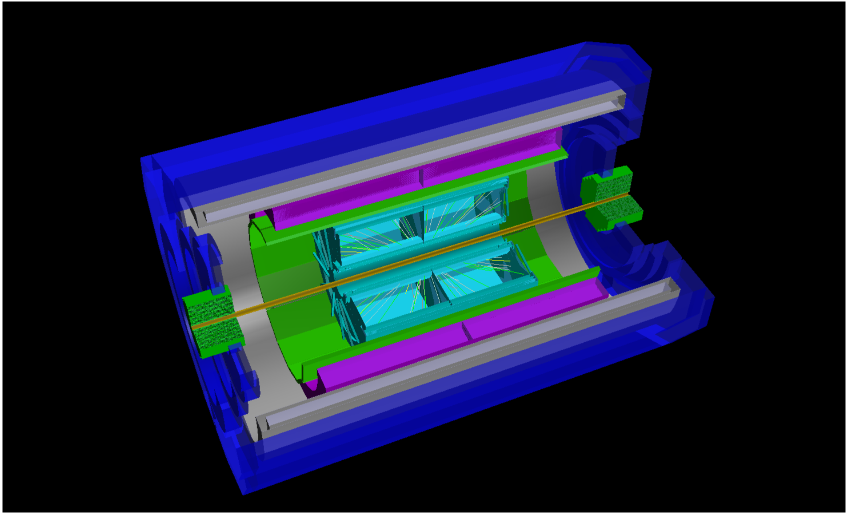
Inner Tracking System (ITS)



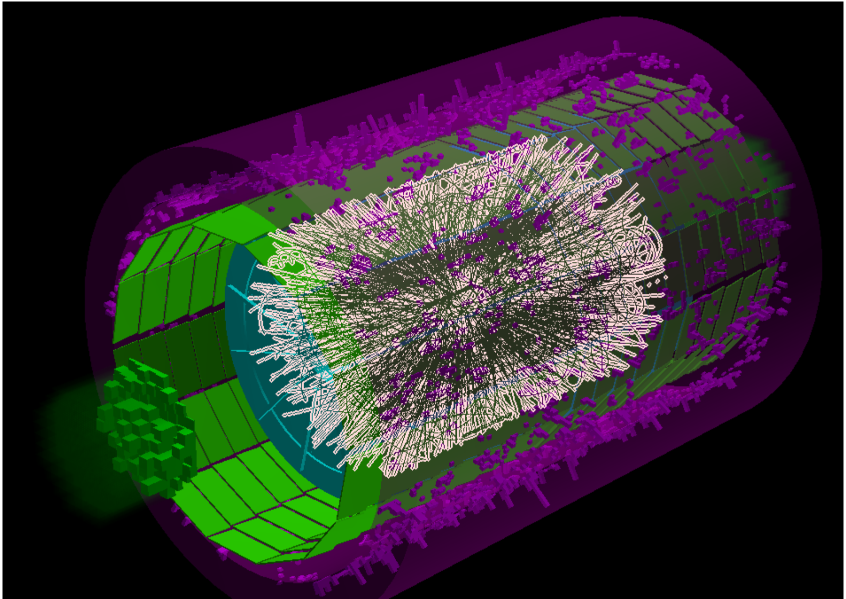


- Track reconstruction enhancement and identification of relatively rare events with (multistrange) hyperons.
- Cooperation with CBM/FAIR, ALICE/CERN.

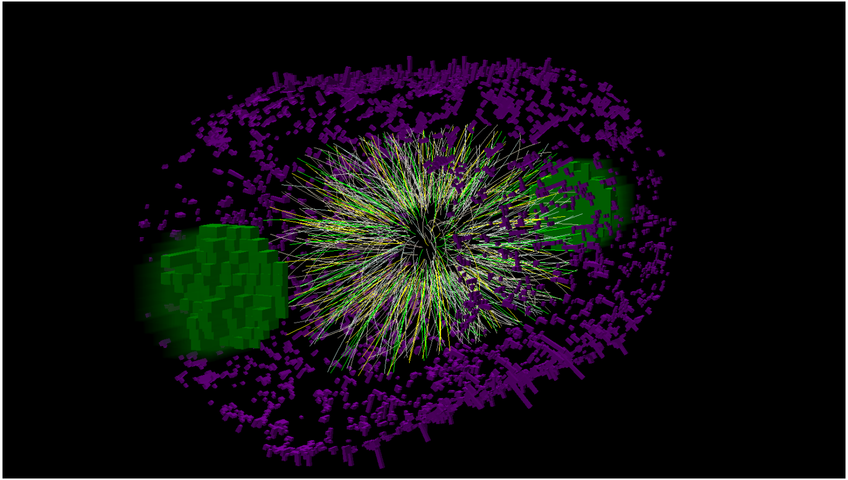
MPD: performance



MPD: performance

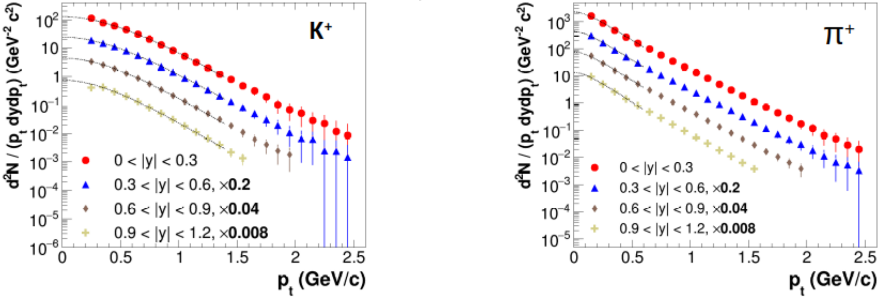


MPD: performance



MPD: performance

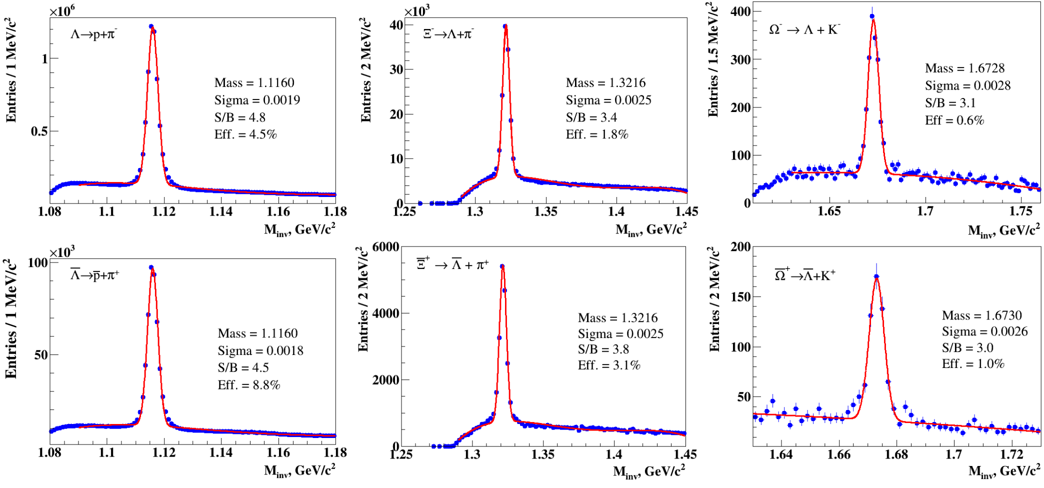
Hadroproduction



- MPD provides large phase-space coverage for identified pions and kaons ($>$ 70% of the full phasespace at 9 GeV)
- Hadron spectra can be measured from p_T=0.2 to 2.5 GeV/c
- Extrapolation to full pT-range and to the full phase space can be performed exploiting the spectra shapes (see BW fits for pT-spectra and Gaussian for rapidity distributions)

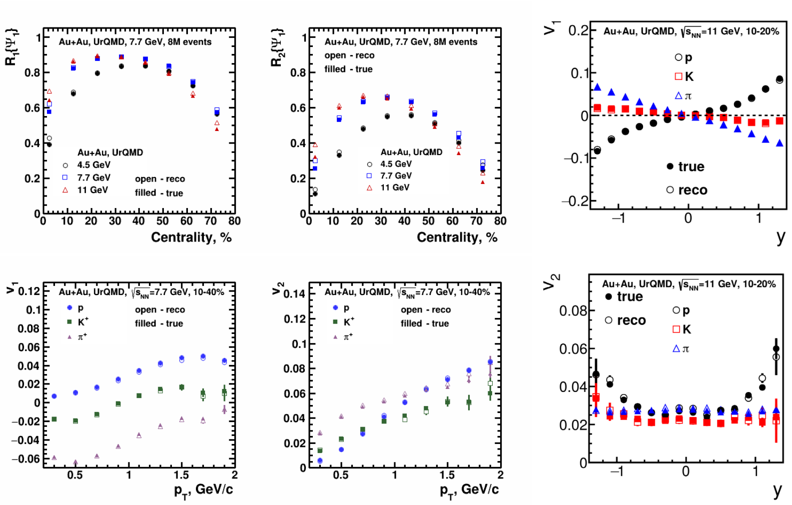
MPD: performance

Strange and multi-strange baryons.



MPD: performance

Collective flow.



Interior of the MPD Hall

Chapter IV

Summary

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Summary

- Density frontier is less explored area of the QCD phase diagram and its study could lead to interesting discoveries.
- In the medium-term prospect the NICA complex will be the only facility in Europe providing high intensity ion beams from p to Bi in the energy range from 2 – 27 GeV (c.m.s.).
- All components of the MPD 1st stage configuration advanced in production, commissioning expected for 2021 and 2022
- Intensive preparations for the MPD Physics programme with initial beams at NICA