

## DENSE COLD BARYONIC MATTER\*

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The possibility to study cold nuclear matter with the density of neutron star core and even larger in the laboratory experiment is discussed. Special rare kinematical trigger for relativistic ion–ion collisions is proposed for such a study. Expected properties of the matter in such unusual conditions and experimental program for its study is discussed. Possible experimental setup and R&D results for position-sensitive neutron detector are presented.

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## 1. Introduction

Perturbative aspects of QCD have been tested up to a few percent. In contrast, non-perturbative aspects of QCD (hadronization, confinement, *etc.*) have barely been tested. The study of the quark matter at different temperature and baryon density is part of effort to consolidate the grand theory of particle physics. A new approach to the laboratory study of extremely dense baryonic matter at low-temperature phase diagram region has been proposed by the FLINT Collaboration [1]. High  $p_t$  central rapidity double cumulative trigger for this study was tested experimentally. Wide experimental program with such a trigger has been discussed in Stavinskiy’s report at WPCF in Kiev [2]. The recent developments of this approach and detectors R&D for such a study are discussed here. Special accent is put on R&D of the position-sensitive neutron detector. Neutron detector is needed for the study of isotopic structure of cold dense nuclear matter and especially for  $np$  femtoscopy.

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## 2. Double cumulative trigger for the study of cold matter

Let us consider the light-ion collision at  $NN$  central mass system energy of the order of few GeV. Extremely high  $p_t$  central rapidity trigger selects flucton–flucton interaction [1] (following Blokhinzev, we will use the term flucton for a few nucleon short-range correlation inside nucleus). The higher  $p_t$  for trigger photon means the larger minimum number of nucleons involved in the flucton–flucton interaction. Nucleons, involved into flucton–flucton interaction will create multibaryon system at the final state. This system is the candidate for cold and dense matter droplet and should be studied. Nuclotron energy range is optimal to study such processes due to two reasons:

1. To identify cold and dense system, it should be separated in the phase space from products of ordinary  $NN$  interactions with mean  $p_t \sim m_\pi$ . It means that the beam energy should be sufficiently large (not smaller than 2–3 GeV/nucleon).
2. To speak about dense cold matter droplet, one needs to obtain as many baryons as possible in the cold and dense final state multibaryon system. Cross section of the process falls dramatically with increasing both fluctons masses and  $p_t$  transferred to multibaryon system. It means that beam energy should be sufficiently small (not larger than 6–10 GeV/nucleon).

For the reason of the study of the process with rare trigger, measurements at fixed target look more promising than at collider experiments. But some points of proposed experimental program are not so critical to beam intensity and can be studied with SPD and MPD detectors.

Correlation measurements between secondary nucleons and trigger particle provide the location of the cold and dense baryonic system in phase space and its temperature. Once identified, this baryonic system should be studied by femtoscopic (or alternative) method to estimate the size of the interaction volume (density of the baryonic system). It is a nontrivial task for femtoscopy due to the both small interaction volume and large 6-dimension density expected for baryonic system produced in selected by trigger flucton–flucton interaction. Methodical problems are planned to be studied at relatively simple MARUSYA-FLINT detector setup at Nuclotron. MARUSYA-FLINT will include all needed detectors (EMCal for trigger, ToF, monitors, *etc.*) but in the version with minimal acceptance. The innovation part of the detector setup will be position-sensitive neutron detector which will be used for identification of charged baryon ( $p, d, t, \text{He}$ ) and neutrons. Full size measurements within proposed physical program are proposed for BM@N.

### 3. Position-sensitive neutron detector

#### 3.1. Motivation

Neutrons are one of the main particle species in the energy range of Nuclotron. The only measurable decay mode for strange baryon  $\Sigma^-$  is  $n + \pi^-$ . For those reasons, it is difficult to say about detector impermeability and isotopic ratio measurements in the baryon sector without neutron identification.

Scattering experiments, where a proton is knocked-out of the nucleus with high momentum transfer and high missing momentum, show that in  $\text{C}^{12}$ , the neutron–proton fluctons are nearly twenty times as prevalent as proton–proton pairs and, by inference, neutron–neutron pairs. This difference between the types of pairs is due to the nature of the strong force and has implications for understanding cold dense nuclear systems such as neutron stars [3].

We also expect significant difference between space-time parameters extracted from femtoscopic analysis of  $np$  and  $pp$ ,  $nn$  pairs.

#### 3.2. Design goals

The mean kinetic energy of neutrons in the energy range of Nuclotron is of the order of several hundreds MeV. The neutron momentum accuracy needed for femtoscopic measurements is of the order of several tens MeV. To meet these conditions, we formulate required features for neutron detector as follows:

1. Neutron energy range from 5 MeV to 200 MeV.
2. Accuracy for neutron momentum 10–20 MeV/ $c$ .
3. Modular structure of detector for correlation measurements.
4. Compact installation modules to create large acceptance detector.
5. Position resolution ( $\sim 1$  cm) one order better than module size.
6. Time resolution 150–200 psec.
7. Gamma–neutron separation.
8. Compact module.

### 3.3. Solution and prototype tests

We propose to create for such a study the position-sensitive neutron detector which would be the next step in neutron identification technique. Except the “standard” PMT, each detector module will be supplied by several APD in different points of scintillator volume. Scintillator volume is hexagonal parallelepiped with the thickness of 200 mm. The distance between opposite-side edges is 175 mm. Each side edge is supplied by optic fibers. APDs are at the end of the fibers. The ratio of signal amplitudes for different diodes provides information on neutron interaction point. Detector is equipped with 3 LED in the front faces for monitoring, PMT XP2041 at the back face for ToF measurements, and temperature sensors for monitoring APD gain.

The difference between neutron interaction point position and light emission points position within scintillator was estimated within **Geant4** simulations and proved to be less than 1 cm up to neutron kinetic energy 200 MeV. Position sensitivity of the neutron detector prototype was tested at ITEP cosmic stand. The data analysis is in progress.

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### REFERENCES

- [1] I.G. Alekseev *et al.*, *Phys. Atom. Nucl.* **71**, 1848 (2008); **78**, 936 (2015).
- [2] A.V. Stavinskiy [for the FLINT Collaboration], *Phys. Part. Nucl. Lett.* **8**, 912 (2011).
- [3] R. Subedi *et al.*, *Science* **320**, 1476 (2008) [arXiv:0908.1514 [nucl-ex]].