Event selection in CSR-ETF U+U collision*

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Abstract Uranium on uranium target (U+U) collision experiment has been proposed to be performed on Cooling Storage Ring (CSR), External Target Facility (ETF), which is to be built at Lanzhou, China, delivering the uranium beam up to 520 MeV/nucleon. It is predicted that the tip-tip U+U collision patterns can produce significant high baryon density and long duration nuclear matter to study the nuclear Equation of State (EoS). As the random orientation in U+U collisions, it is necessary to select the interested tip-tip events from the large trivia background. A Relativistic Transport (ART1.0) Model is applied to compute the random mini-biased U+U collisions to select our most favorable tip-tip events. It is found that applying various combination cut on the forward neutron multiplicity and forward charged particle multiplicity of the random U+U mini-biased sample, we can select the tip-tip configuration with certain purity and efficiency.

Key words uranium, CSR, ETF, nuclear EoS, event selection, Lanzhou

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1 Introduction

Heavy ion collisions performed at the BEVALAC/LBNL and SIS/GSI[1, 2] in last two decades were used to produce hot and compressed nuclear matter to learn more about the nuclear equation of state (EoS)[3, 4] at high baryon density and low temperature region of the phase diagram. Although we have made great efforts to study the nuclear EoS, theoretically and experimentally, a solid conclusion can hardly be made. Then, it is still worthwhile to systematically study the collision dynamics as well as the EoS observables. Recently, for better understanding of the nuclear matter phase diagram and EoS in high net-baryon density region, it is proposed to collide uranium on uranium target at CSR-ETF with a beam kinetic energy of 520 MeV/nucleon[5].

Uranium is the largest deformed stable nucleus, and has approximately an ellipsoid shape with the long and short semi-axis given by $R_{\rm l} = R_0(1+2\delta/3)$ and $R_{\rm s} = R_0(1-\delta/3)$, respectively, where $R_0 = 7$ fm is the effective spherical radius and $\delta = 0.27$ is the deformation parameter[6]. Consequently, one has $R_{\rm l}/R_{\rm s} = 1.3$. The so-called tip-tip and body-body patterns with the long and short axes of two nuclei are aligned to the beam direction respectively, are the two extreme collision orientations[7], see Fig. 1 for illustration. Recently, we have studied the stopping effects[8] of the two extreme collision orientations. It is demonstrated that the maximum attainable central baryon density, collective flow, thermalization et al, are avail circumstance to explore the nuclear EoS. In that paper, we did't consider the selection of the two orientations from the random U+U collision quantitatively. In our study, central collisions of the tip-tip configuration, which can be used to produce high baryon density matter without any increase in beam energy, is our most desired configuration. However, no pure idea tip-tip event sample is available in real experiment, it has to be selected by using combina-

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tion of triggering and off-line event selection. In this article, we have made appropriate cut on the forward charged particle multiplicity ($\theta \leqslant 90^\circ$) and forward neutron multiplicity($\theta \leqslant 20^\circ$) in the lab frame, which may be used as hardware trigger in real experiment, to select the near tip-tip orientation for certain purity and efficiency.

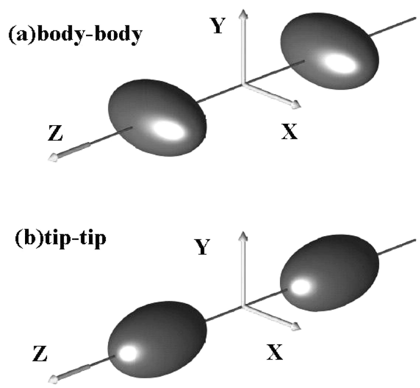

Fig. 1. (Color Online) (a) body-body collisions (b) tip-tip collisions.

The ART1.0 model[9, 10] based on Boltzmann-Uehling-Uhlenbeck (BUU) model[11] has a better treatment of mean field and Pauli-Blocking effects[11] than cascade models[12]. The fragment production mechanism and partonic degree of freedom are not present in the ART1.0 model. A soft EoS with a incompressibility coefficient of $K = 200$ MeV is used throughout the calculation and the beam kinetic energy of uranium nuclei is set to 520 MeV/nucleon if not specifically indicated. In the next section, we discuss some experimental observable distributions, such as the forward charged particle multiplicity and forward neutron multiplicity. In Sec. 3, we present the results. We summarize our results in Sec. 4.

2 Global on-line trigger distribution

Considering the particles produced from fixed target experiment mainly distributed in the forward region, we choose two experimental observables as hardware trigger: the forward charged particle multiplicity and the forward neutron multiplicity with the particle polar angle $\theta \leqslant 90^\circ$ and $\theta \leqslant 20^\circ$ in the lab frame respectively to select the near tip-tip configuration On-Line. It is expected that the desired tip-tip orientation events can be obtained with a certain purity and efficiency by making appropriate cut on the two experimental variables[13—15].

2.1 Forward neutron multiplicity distribution

Figure 2 shows the forward neutron multiplicity ($\theta < 20^\circ$) distribution of the mini-biased random U+U collisions. The neutron can be covered and effectively detected by the forward neutron wall located in the forward region of the CSR-ETF. In our previous study, the forward neutron multiplicity has a good linear dependent on impact parameter b near the central collisions[8], decreasing with the neutron multiplicity. If we make a cut on the small forward neutron multiplicity, the event sample with small impact parameter b can be obtained.

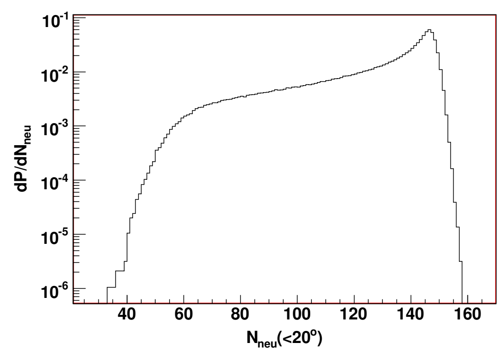

Fig. 2. Forward neutron multiplicity distribution for mini-biased random U+U collisions.

2.2 Forward charged particle multiplicity distribution

Figure 3 illustrates the forward ($\theta \leqslant 90^\circ$) charged particle multiplicity distribution of mini-biased random U+U collisions. The forward charged particles can be detected and identified by the forward detectors, such as TOF, Tracking Champers et al.

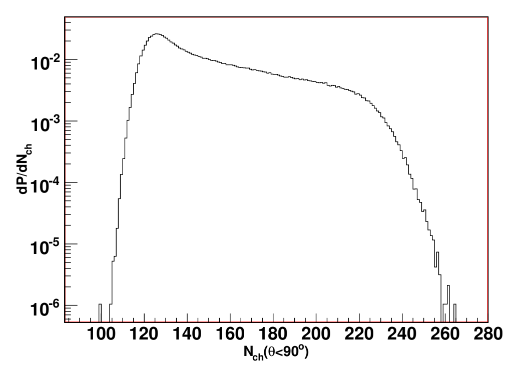

Fig. 3. Forward charged particle multiplicity ($\theta \leqslant 90^\circ$) distribution for mini-biased random U+U collisions.

3 Results

In the random U+U experiment, we hope to select certain ranges of angles and impact parameter. The orientation of the projectile and the target uranium nucleus in the colliding pair is determined by the two angles $(\theta_{\rm p},\phi_{\rm p})$ and $(\theta_{\rm t},\phi_{\rm t})$, respectively. The two polar angles $\theta_{\rm p}$ and $\theta_{\rm t}$ represent the orientation of the symmetry axis relative to the beam direction, which are uniformly distributed in $[0,\pi]$. The two azimuthal angles $\phi_{\rm p}$ and $\phi_{\rm t}$ represent the rotation about the beam direction, and uniformly distributed in $[0,2\pi]$. For our goal, the most desired events are the tip-tip central collision, which can produce high baryon density and long duration nuclear matter. For illustration and simplicity, we choose a range of definition for near tip-tip configuration: $b \leqslant 2$ fm, $\theta_{\rm p},\theta_{\rm t} \in [0,20°] \cup [160°,180°]$. The two triggers mentioned above are used to select the defined the near tip-tip configuration.

In the below, we select the near tip-tip configuration events sample from mini-biased random U+U collisions. As the impact parameter b has a good linear dependence of the forward neutron multiplicity at small b, decreasing with the neutron multiplicity, we use a low forward neutron count for the initial centrality cut and also apply cut on the high charged particle multiplicity to calculate the purity and efficiency of the interested events sample. To understand the calculation of the purity and efficiency correctly, we use formulas to present it clearly. The formulas are written as:

$$\mathrm{Purity}(N_{\rm neu},N_{\rm ch}) = \frac{N_{\rm Interested}(m<N_{\rm neu},n>N_{\rm ch})}{N_{\rm sub-sample}(m<N_{\rm neu},n>N_{\rm ch})}, \tag{1}$$

$$\mathrm{Efficiency}(N_{\rm neu},N_{\rm ch}) = \frac{N_{\rm Interested}(m<N_{\rm neu},n>N_{\rm ch})}{N_{\rm mini-biased}}. \tag{2}$$

When a pair of ($N_{\rm neu}$, $N_{\rm ch}$) are fixed, the $N_{\rm sub-sample}$ are the number of those events with forward neutron multiplicity below the $N_{\rm neu}$ and also with forward charged particle multiplicity above the $N_{\rm ch}$. The other two quality $N_{\rm interested}$ and $N_{\rm mini-biased}$ are the number of the interested events in the sub-sample and the number of total mini-biased events, respectively. Then the purity and efficiency are defined as the percentage of interested events in the sub-sample and the total mini-biased events sample, respectively.

Figure 4 shows the purity of the near tip-tip configuration events in the sub-sample, which are selected from the primary mini-biased random U+U events sample by applying combination cut on the low neutron multiplicity and high charged particle multiplicity. It is found that various purity can be achieved by different combination cut of the $N_{\rm neu}$ and $N_{\rm ch}$, and the maximum purity is about 21% with $N_{\rm neu} \sim 40$. When the $N_{\rm neu} < 45$, the additional cut on the $N_{\rm ch}$ has little effect on the purity comparing to the large effect of the $N_{\rm neu} > 45$. It means that the purity can hardly be improved by further cut high multiplicity when the $N_{\rm neu}$ is low enough. Fig. 5 illustrates the selection efficiency of the near tip-tip configuration. As we only concentrate the near central collision events ($b \leqslant 2$ fm), there exists large trivia background ($b > 2$ fm) leading to the significant low efficiency. Comparing the Fig. 4 with Fig. 5, we find that the higher purity is required, the lower efficiency we can obtain. For high purity, we should make strict cut on the two triggers, then the number of the interested events is small. For a certain required purity, the corresponding maximum selection efficiency and cut condition are calculated for $b \leqslant 2$ fm events sample and near tip-tip configuration sample, respectively shown in the Tables 1 and 2.

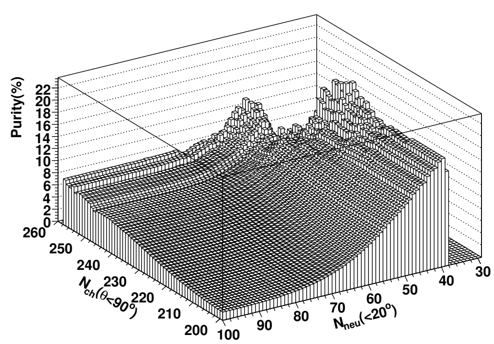

Fig. 4. Purity(%) as a function of various $N_{\rm neu}$ and $N_{\rm ch}$ cut for selection of near tip-tip configuration in sub-sample.

Table 1. Require $b \leqslant 2$ fm only.

($N_{\rm neu}$,$N_{\rm ch}$)	(Pur., Eff.)(%)
(48,247)	(100, 1.79×10^{-3})
(54,225)	(95, 0.169)
(59,223)	(90, 0.456)
(61,217)	(85, 0.745)
(63,213)	(80, 1.001)
(71,209)	(60, 1.746)

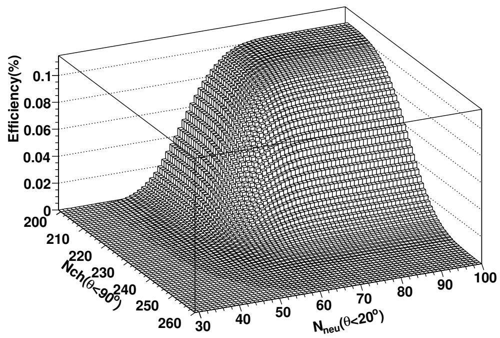

Fig. 5. Efficiency(%) as a function of different $N_{\rm neu}$ and $N_{\rm ch}$ cut for selection of near tip-tip configuration.

Table 2. Near tip-tip configuration.

($N_{\rm neu}$,$N_{\rm ch}$)	(Pur., Eff.)(%)
(41,234)	(21, 2.39×10^{-4})
(41,236)	(20, 1.82×10^{-4})
(44,200)	(15, 1.67×10^{-3})
(50,218)	(12, 1.01×10^{-2})
(55,200)	(9, 3.13×10^{-2})
(84,238)	(5, 1.26×10^{-2})

The method using the two on-line triggers is a rough estimation of the selection purity and efficiency of our most favorable configuration: the near tip-tip events sample, and further study is needed to choose more effective triggers,such as stopping power ration, to improve the purity and the efficiency. We postpone this for a longer publication.

4 Summary

The random U+U collision experiment will be performed on Lanzhou CSR-ETF with a beam energy of 520 MeV/nucleon. To select the near tip-tip configuration from mini-biased events sample, we choose two on-line triggers: the forward neutron multiplicity $N_{\rm neu}(\theta\leqslant 20°)$ and forward charged particle multiplicity $N_{\rm ch}(\theta\leqslant 90°)$. By applying combination cut on the $N_{\rm neu}$ and $N_{\rm ch}$, we obtain a various of selection purity and efficiency. The maximum selection purity of the near tip-tip configuration is about 21% when the $N_{\rm neu}\sim 40$. The method is just a rough estimation of the purity and efficiency, further studies with much more effective on-line or off-line triggers should be carried out in later publication.

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