Directed flow in Ni+Ni and Au+Au collisions and the QMD simulation

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ibs 기초과학연구원 Institute for Basic Science

RISP Rare Isotope Science Project

Contents

RAON and LAMPS

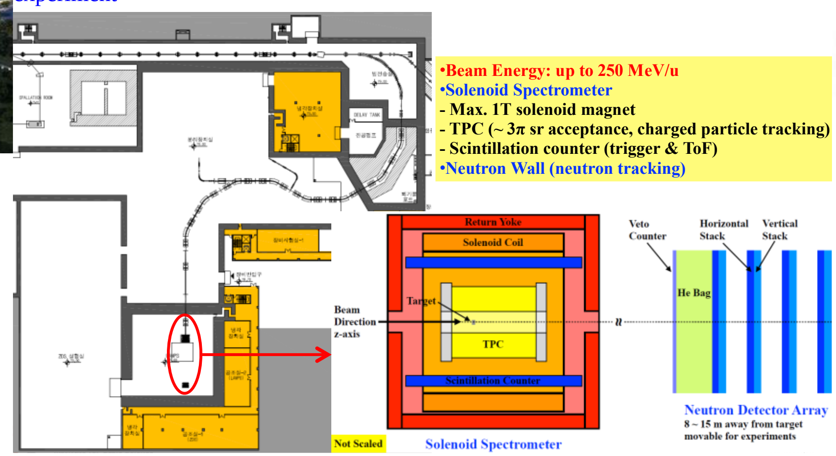
Basic design was finished in Dec. 2015
A construction company was selected in

RAON

Large Acceptance Multi-Purpose Spectrometer (LAMPS)

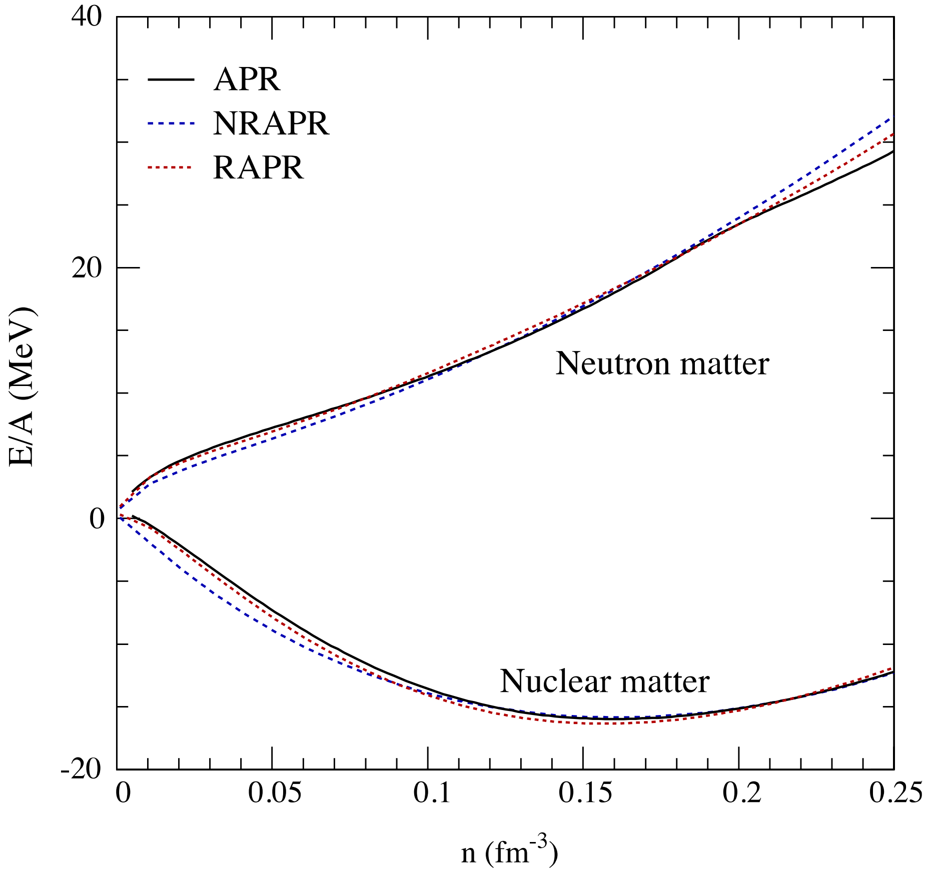
•Main facility for nuclear matter and nuclear reaction studies with intermediate energy stable and rare isotope beams

•Main Research Subject:
Study of nuclear symmetry energy at supra-saturation density via heavy-ion collision experiment



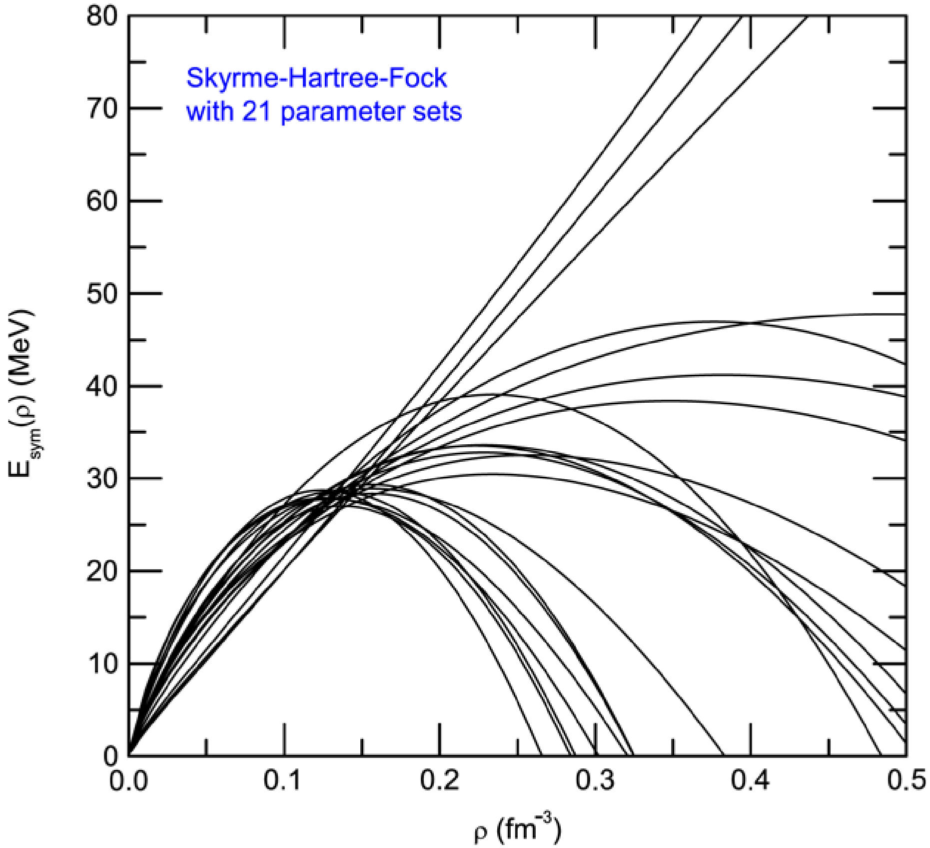
from Y.J.Kim's slide

Nuclear Equation of State



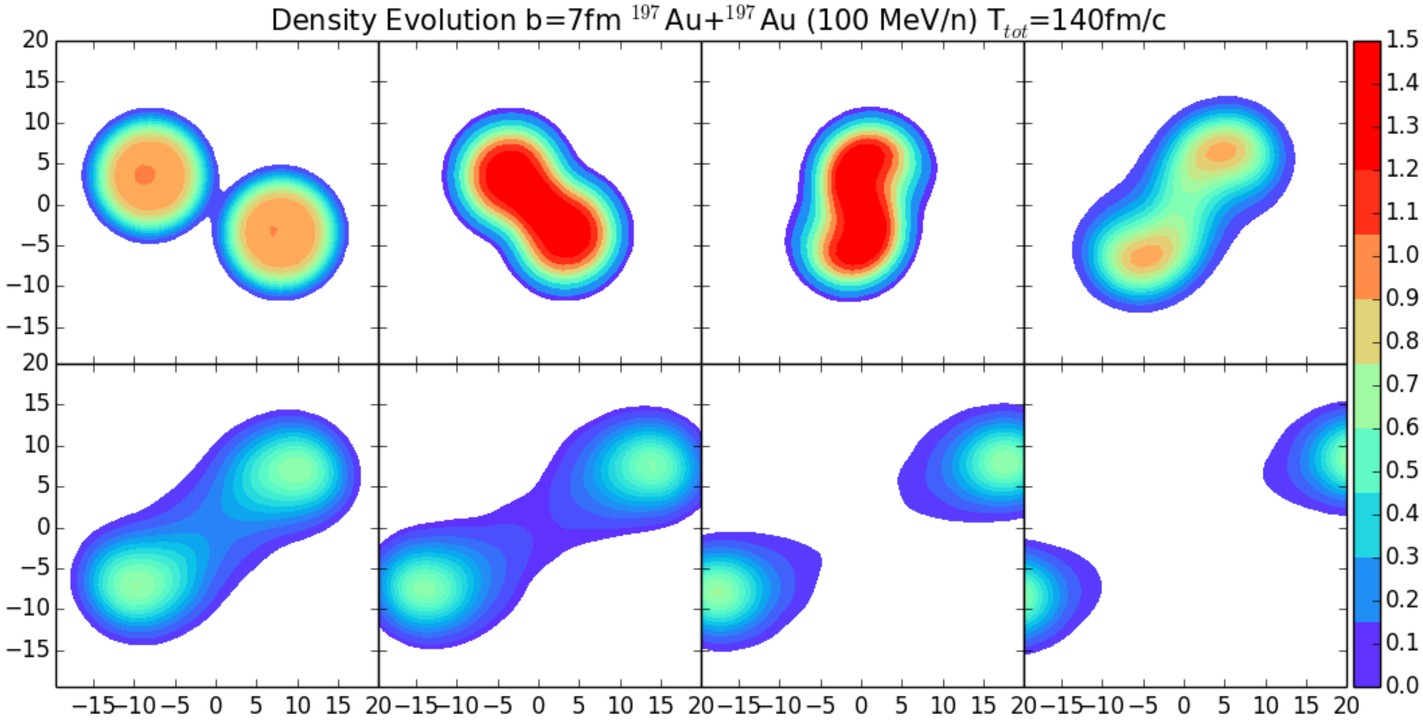
ref. A.W.Steiner et al. Phys.Rep. 411,325

Nuclear Equation of State



ref. B.-A.Li et al. Phys.Rep. 464,113

Au (100 MeV/n)+Au at b=7fm



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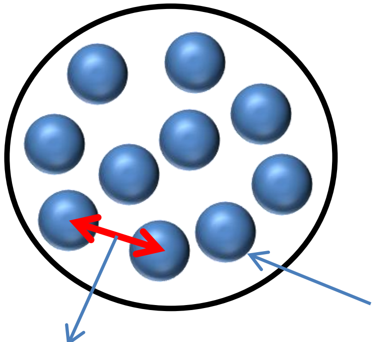
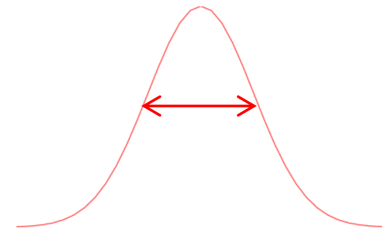
Initialization

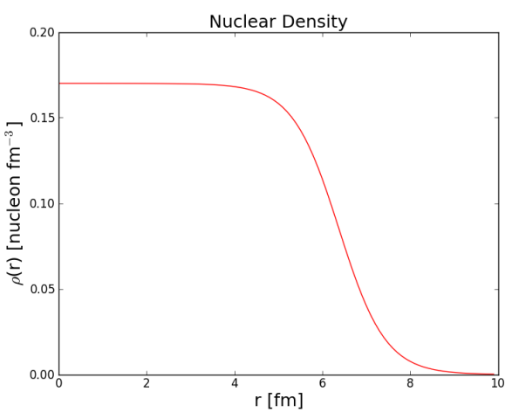


d > 1.5 fm

<Gaussian distribution>



$$f_i(\vec{r},\vec{p},t) = \frac{1}{(2\pi\sigma_r\sigma_p)^3}\exp\left[-\frac{(\vec{r}-\vec{r_i}(t))^2}{2\sigma_r^2} - \frac{(\vec{p}-\vec{p_i}(t))^2}{2\sigma_p^2}\right]$$



<Density distribution>
- Wood-Saxon function

$$\rho = \rho_0\left[1+\exp\left\{\frac{r-R}{a}\right\}\right]^{-1}$$

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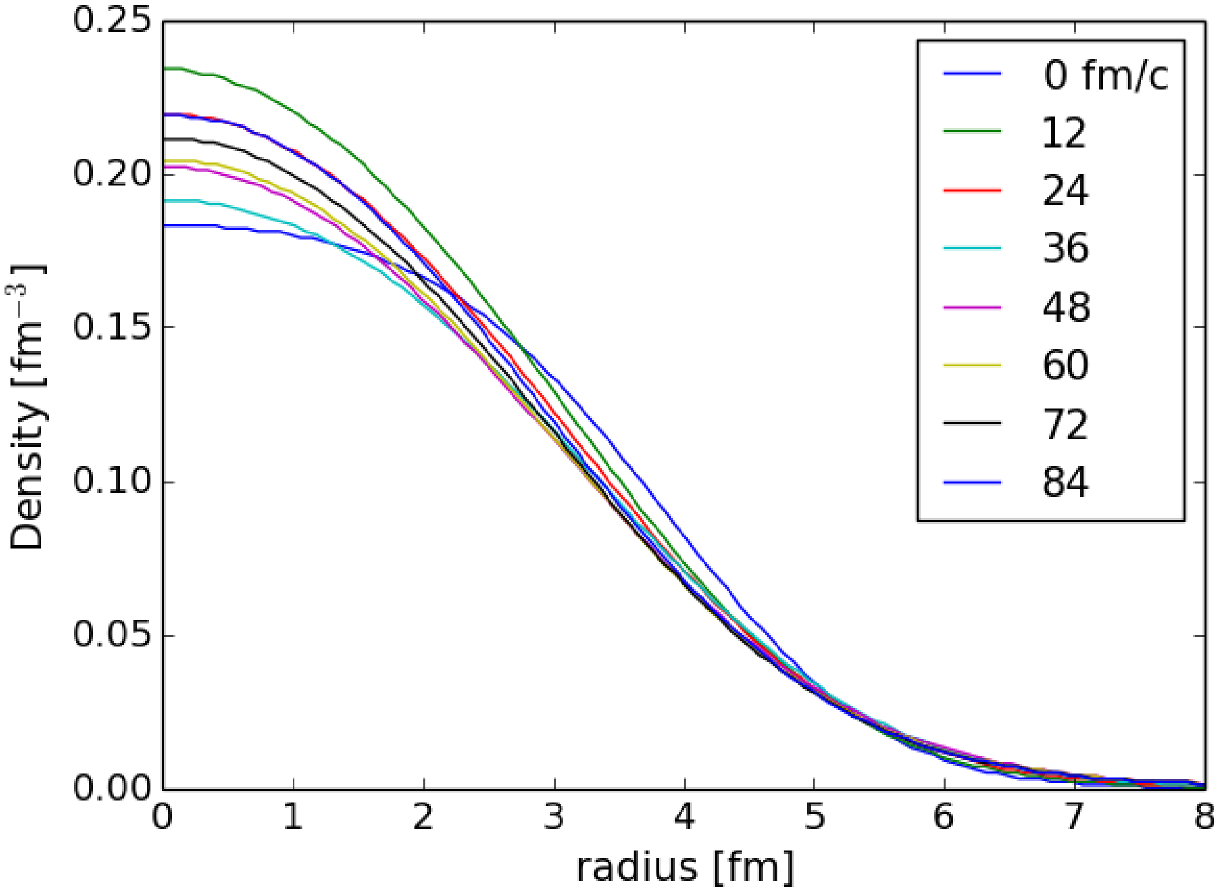
Stability of Ni Nucleus



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Propagation

$$H = \sum_i \frac{\vec{p}_i^{\,2}}{2m} + U^{2body} + U^{3body} + U^{surf} + U^{sym} + U^{Coul}$$

Skyrme parametrization for NN potential

$$U^{2body} = \frac{\alpha}{2\rho_0} \sum_{i,j\neq i} \rho_{ij},$$

$$U^{3body} = \frac{\beta}{\gamma+1} \sum_i \left(\sum_{j\neq i} \frac{\rho_{ij}}{\rho_0} \right)^{\gamma},$$

$$U^{surf} = \frac{g_{surf}}{2\rho_0} \sum_{i,j\neq i} \nabla^2_{r_i}(\rho_{ij}),$$

$$U^{sym} = \frac{g_{sym}}{2\rho_0} \sum_{i,j\neq i} [2\delta_{\tau_i\tau_j} - 1]\rho_{ij},$$

$$U^{Coul} = \frac{e^2}{2} \sum_{i,j\neq i} \frac{1}{|\vec{r}_i - \vec{r}_j|} \mathrm{erf}\left(\frac{|\vec{r}_i - \vec{r}_j|}{2\sigma_r} \right) \quad (i, j \text{ for protons})$$

K(MeV)	α (MeV)	β(MeV)	γ	EOS
200	-356	303	7/6	Soft
380	-124	70.5	2	Hard

Ref.) M. Papa PRC 64(2010)024612

<Equation of Motion>

$$\frac{d\vec{r}_i}{dt} = \frac{\vec{p}_i}{\mu} \qquad \frac{d\vec{p}_i}{dt} = -\nabla_{r_i} U$$

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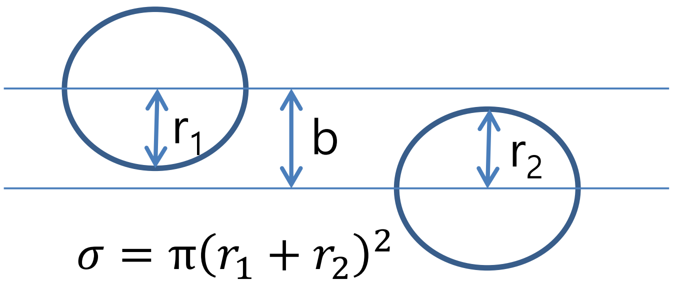
N-N Collision



$\sigma = \pi(r_1 + r_2)^2$

In classical scattering,

$b < r_1 + r_2$

➡ *Two particles are always scattered.*

In our model,

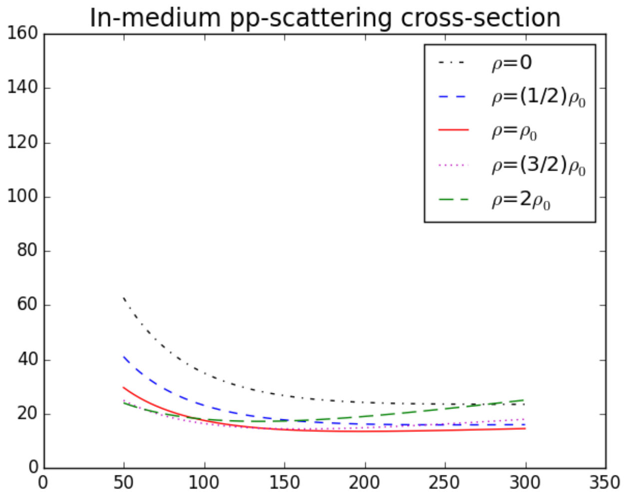
$b = \sqrt{\sigma_{tot}/(10 \times \pi)}, \qquad (b\text{: [fm]}, \sigma\text{: [mb]})$

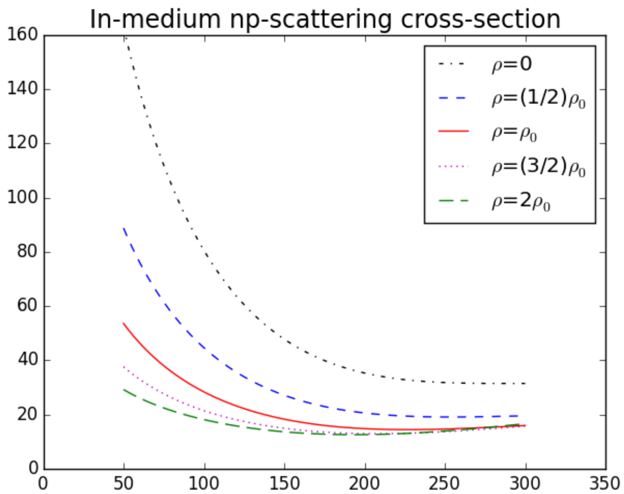
➡ **If a distance, d, between two nucleons is smaller than b, d<b, a collision is always tried.**

Here, σ_{tot} is in-medium cross-section.

$$\left|\frac{\Delta \vec{r} \cdot \vec{p}}{p}\right| < \left(\frac{p}{2m_1} + \frac{p}{2m_2}\right)\frac{\delta t}{2}$$

N-N Collision





Ref.) G.Li and R.Machleidt PRC 48, 1702, PRC 49, 566

$$\sigma_{pp-tot}(E_{lab},\rho) = [23.5 + 0.00256(18.2 - E_{lab}^{0.5})^{4.0}] \times \frac{1.0 + 0.1667 E_{lab}^{1.05}\rho^3}{1.0 + 9.704\rho^{1.2}}$$

$$\sigma_{np-tot}(E_{lab},\rho) = [31.5 + 0.092|20.2 - E_{lab}^{0.53}|^{2.9}] \times \frac{1.0 + 0.0034 E_{lab}^{1.51}\rho^2}{1.0 + 21.55\rho^{1.34}},$$

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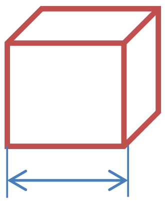
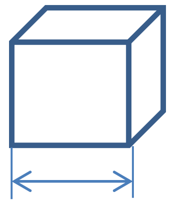
Pauli blocking

<x-space>



$\sqrt{2\pi\hbar\sigma_r/\sigma_p}$

<p-space>

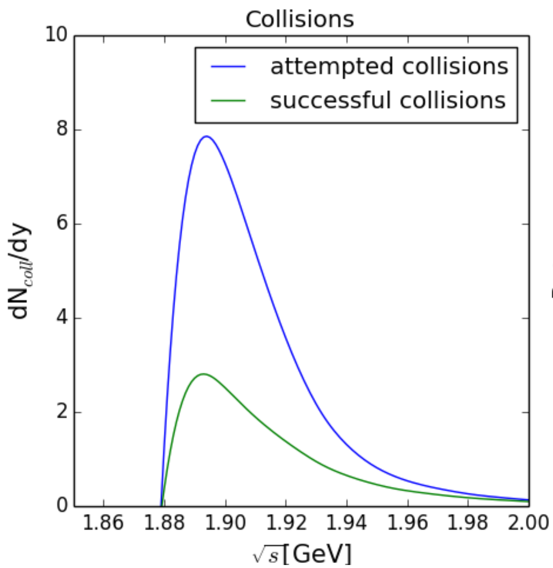


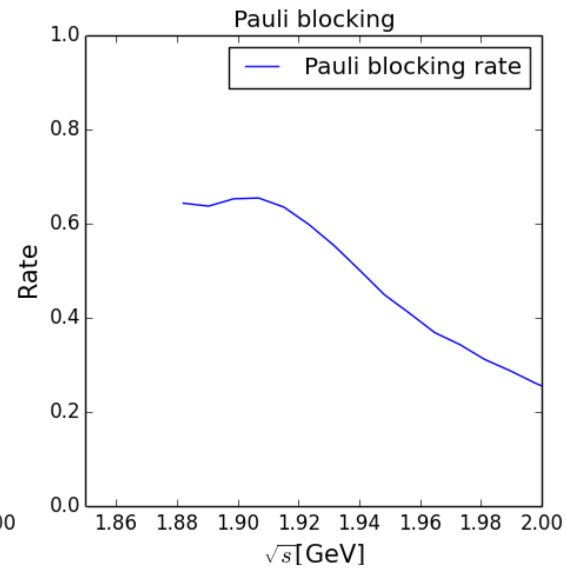
$\sqrt{2\pi\hbar\sigma_p/\sigma_r}$

<Phase space density for *i* th particle>

$$\bar{f}_i \equiv \sum_j \delta_{\tau_i,\tau_j}\delta_{s_i,s_j}\int_{h^3} f_i(\vec{r},\vec{p})\; d^3r d^3p$$

Occupation number





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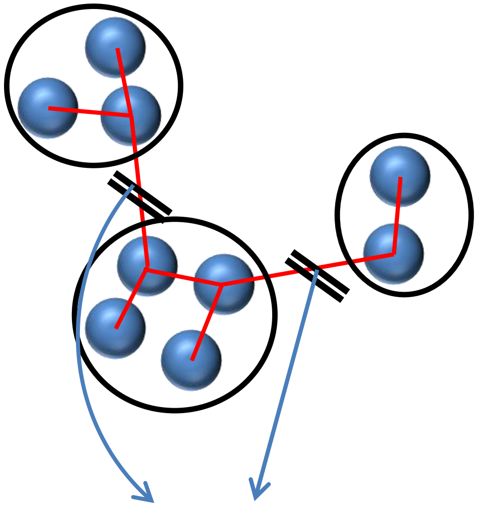
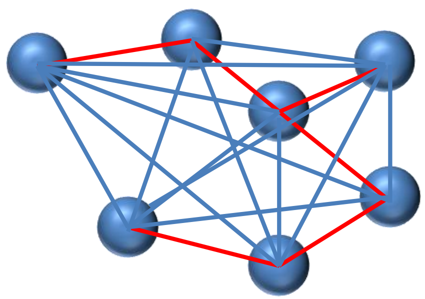
Cluster Recognition



Disconnected if a length is larger than 3.5 fm.

<Minimum Spanning Tree (MST)>



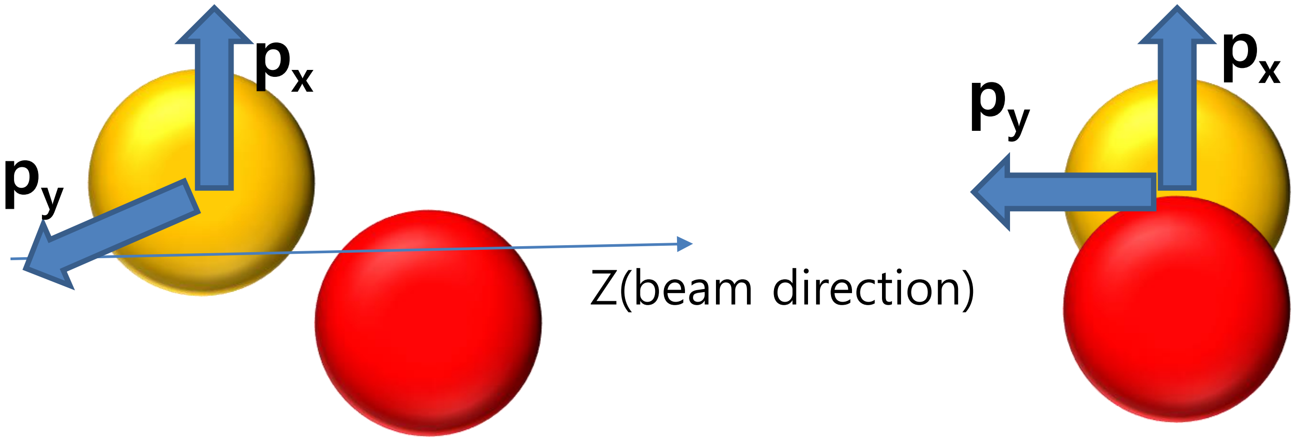
Differential Flow

$$u = (\gamma, \vec{\beta}\gamma); \qquad u_t = \beta_t \gamma$$

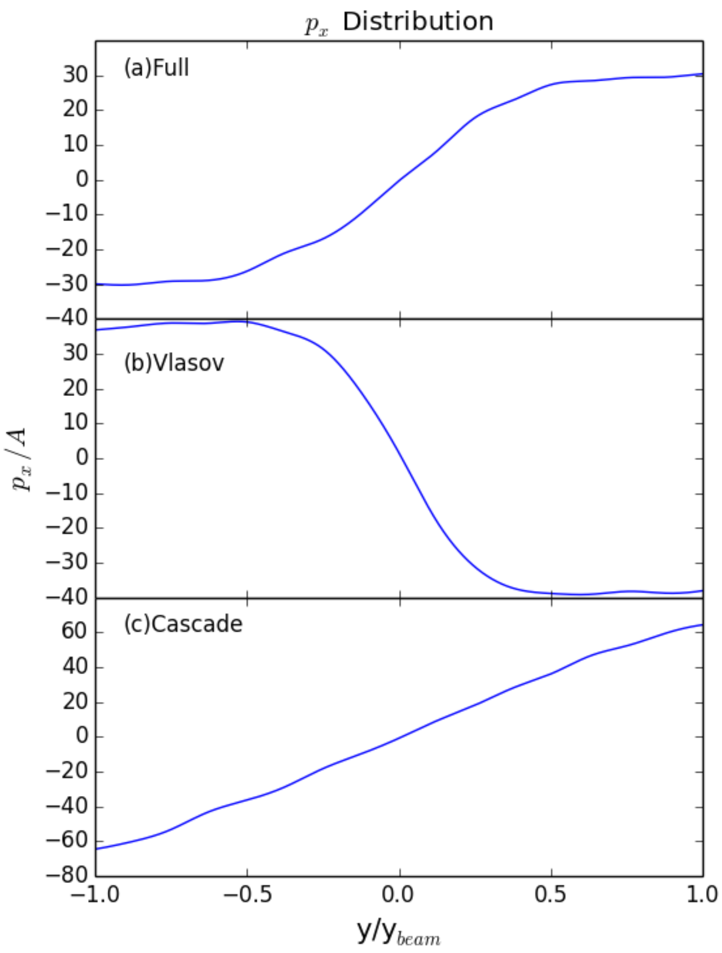
$$\frac{dN}{u_t\, du_t\, dy\, d\phi} = v_0\left[1 + 2v_1 \cos(\phi) + 2v_2 \cos(2\phi)\right]$$

$$v_0 = v_0(y, u_t); \qquad v_1 = v_1(y, u_t); \qquad v_2 = v_2(y, u_t)$$

$$v_1 = \left\langle \frac{p_x}{p_t} \right\rangle = \langle \cos(\phi) \rangle; \qquad v_2 = \left\langle \left(\frac{p_x}{p_t}\right)^2 - \left(\frac{p_y}{p_t}\right)^2 \right\rangle = \langle \cos(2\phi) \rangle$$



p_x distribution



Potential + Collisions

Potential only

Collisions only

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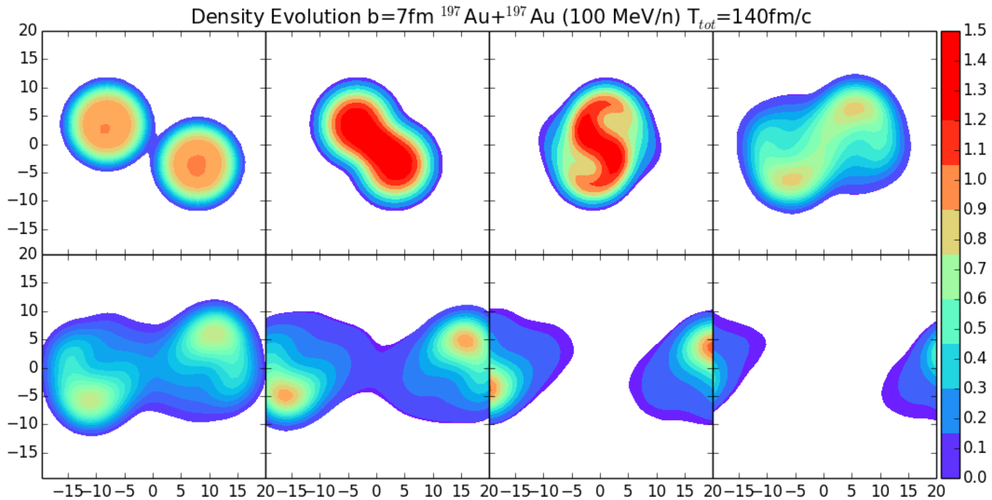
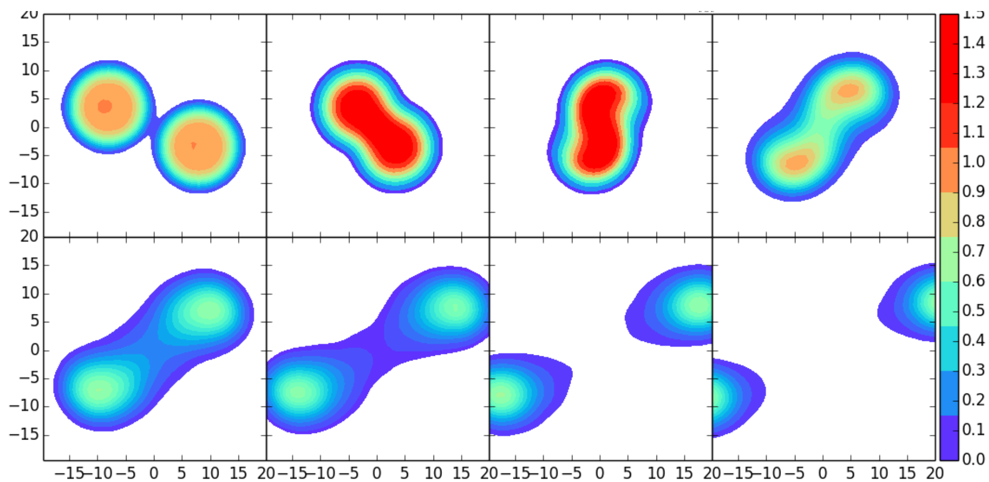
Role of NN Collision

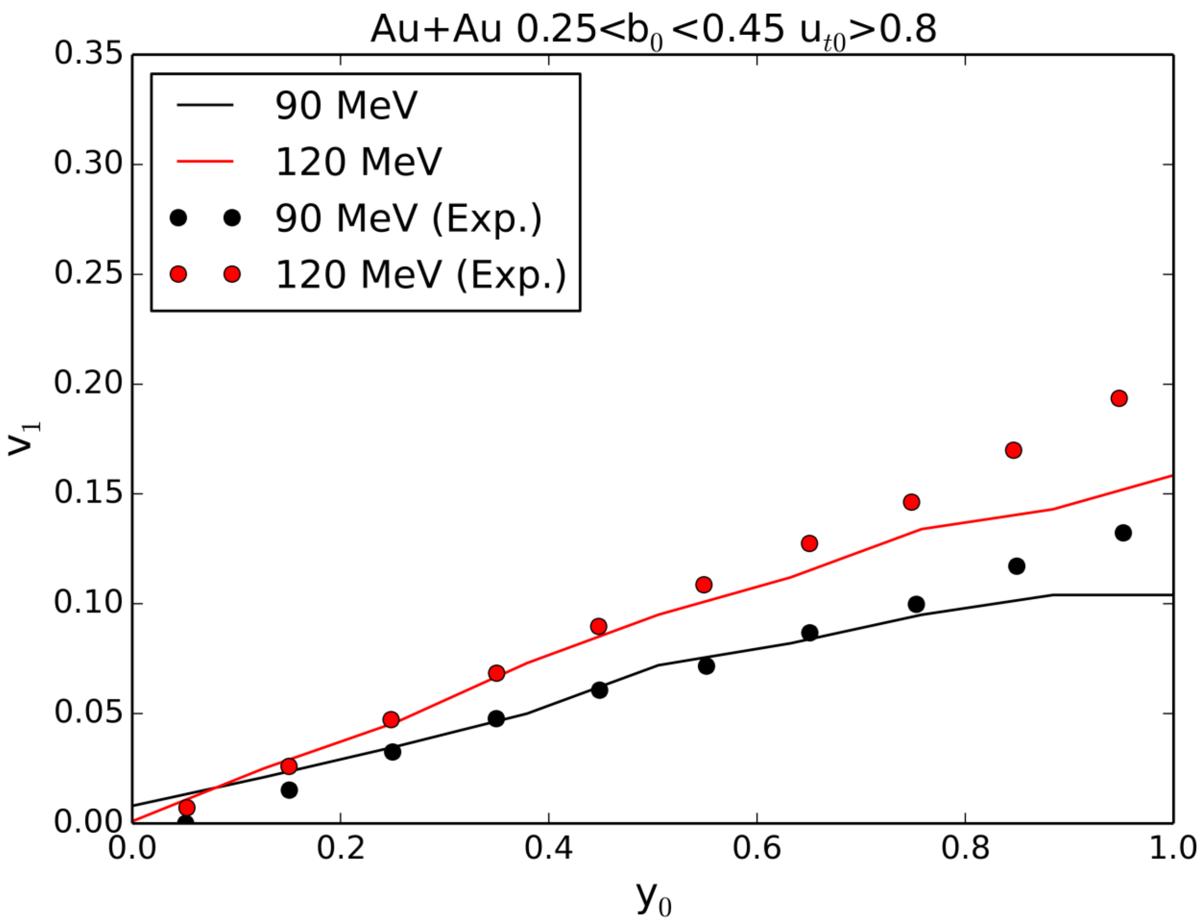


w/o collisions



w/ collisions

Comparison with FOPI data



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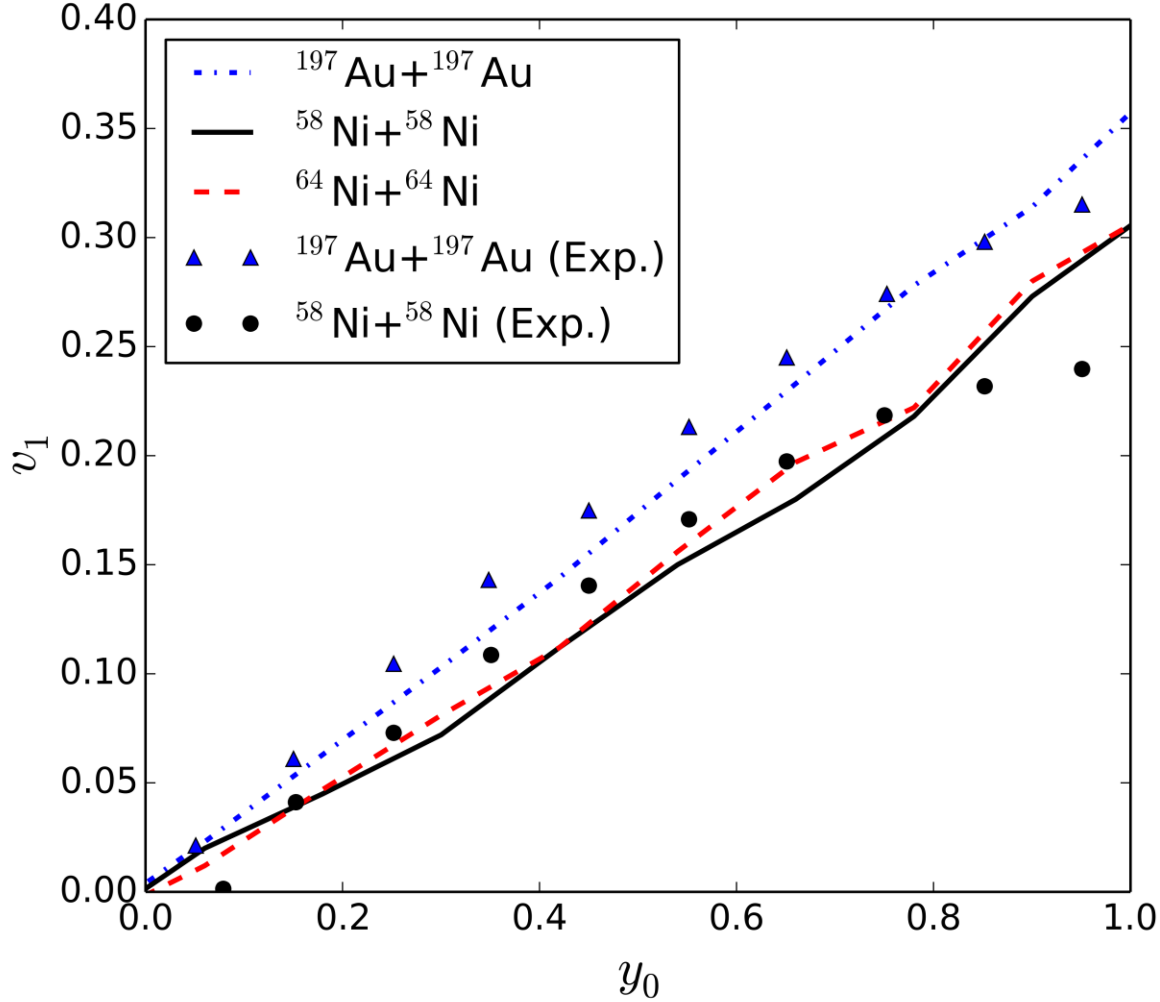
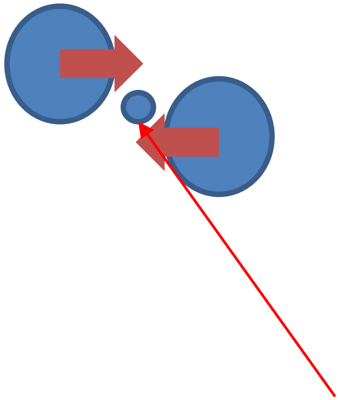
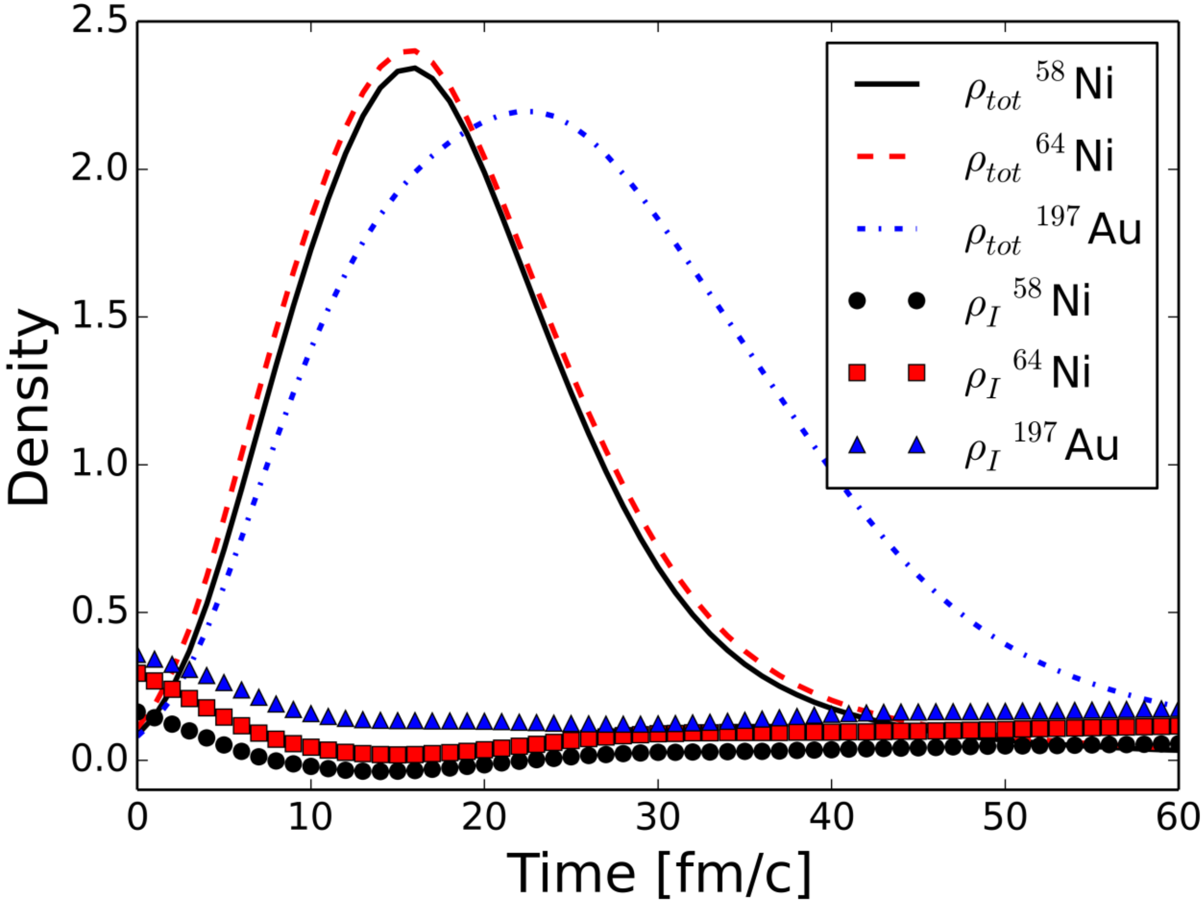
v_1 of Ni+Ni and Au+Au

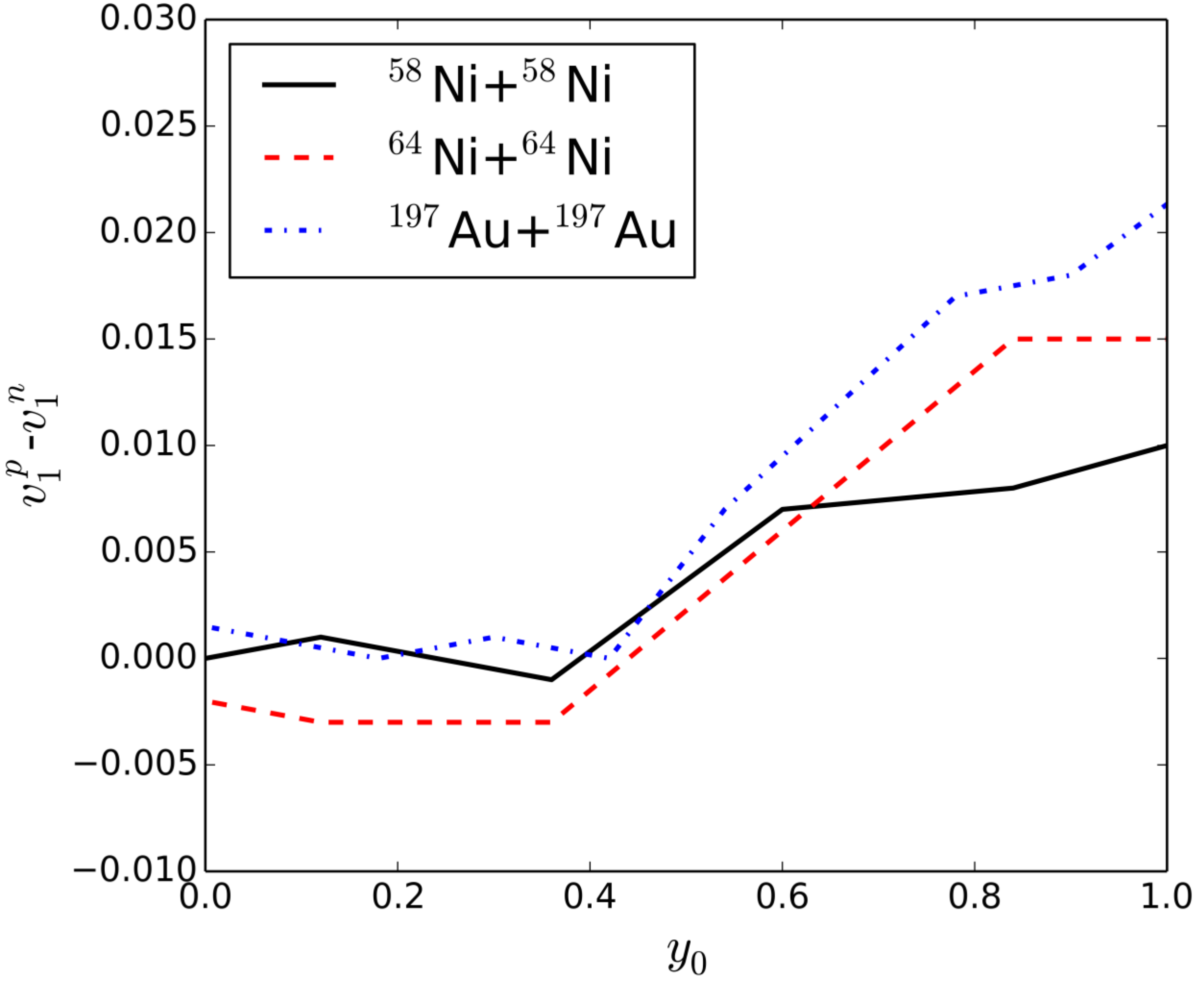


Density at Collision Center





Difference between proton and neutron



Summary and Outlook

❖ RAON facility will provide opportunities to study isospin asymmetric matters and exotic nuclei by heavy-ion collisions induced by neutron-rich beams.

❖ As a reliable theoretical tools, we need a transport model.

❖ Differential flow is one of the probes for the symmetry potential study.

❖ We need more study to find an observable which is sensitive to the change of the curvature of symmetry potential.

Thank you for your attention!!

Backup Slides

Transport model