Orbital dispersion and deflection of fragmentation products at 290 MeV/u

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Abstract.

Orbital dispersion and deflection of fragmentation products, reduced from their transverse-momentum (P_T) distributions, are studied. Measurements of P_T distributions of fragments, which were produced from Ar and Kr beam at E = 290 MeV/u with various targets, have been performed as a function of longitudinal momentum (P_L) at NIRS. In principle, P_T distribution, observed with light target, shows no additional dispersions, which are proposed in the previous studies. On the other hand, obvious orbital deflection, observed with heavy targets, implies the dominant contribution of Coulomb repulsion.

1. Object

A. Reaction mechanism of fragmentation process at E=290MeV/u
- Contribution of Coulomb-nuclear force
- Contamination dissipative process

B. Nuclear data used in simulation code
- Production and transport of RI-beams
  Estimation of intensity and quality of RIBs
- Heavy ion transfer in materials
  Radiation shield at RIB facility, Galactic cosmic ray, heavy ion therapy, ...

2. Momentum distribution of PLFs

A. Production of projectile-like fragments

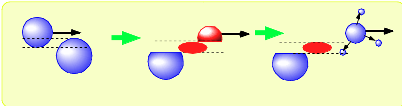


Fig. 1 Participant-spectator scheme

B. Momentum dist. at relativistic energies (E > 1GeV/u)
- Isotopic Gaussian-like distribution
- Participant-spectator scheme is dominant.
- Momentum dispersion induced by Fermi-momentum proposed by A.S. Goldhaber [1)]

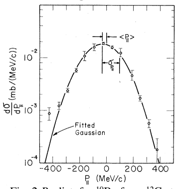


Fig. 2 P_L dist. for ^{10}Be from ^{12}C at 2.1 GeV/u on a Be target. [2)]

$$\sigma_L = \sigma_T = \sigma_{GH} = \sigma_0\sqrt{\frac{A_F(A_P - A_F)}{A_P - 1}},\quad \sigma_0 \sim 100\,(\mathrm{MeV/c})$$

C. Momentum dist. at lower energies (E ~ 100 MeV/u)
- Anisotropic dist.
- Additional dispersion in P_T dist.

Dispersion due to orbital deflection prior to breakup [3)]

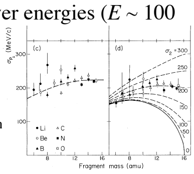


Fig. 3 Obs. σ_T for each isotope for (c) ^{16}O+Al, (d) ^{16}O+Au @92.5 MeV/u [3)]

$$\sigma_T = \sqrt{\sigma_L^2 + \sigma_D^2}$$

$$\sigma_D = \sigma_{D0}\sqrt{\frac{A_F(A_f - 1)}{A_P(A_P - 1)}},\quad \sigma_{D0} = 195\,(\mathrm{MeV/c})$$

Dispersion due to Coulomb final state interaction between fragment and protons dissociated from proj. [4)]

- Asymmetric P_L dist. with a tail on the low-momentum side [5)]

Contamination of dissipative process is expected, but physical models have not been established.

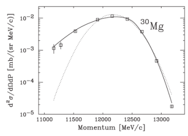


Fig. 4 Typical fragment P_L distribution and fitting results of ^{30}Mg data [6)]

- Correlation between σ_T and P_L?
- Contribution of Coulomb-nuclear force?

3. Experimental

A. Preparation of incident beam

^{40}Ar and ^{84}Kr beam with 290 MeV/u were prepared by HIMAC facility at NIRS.

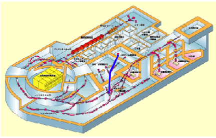
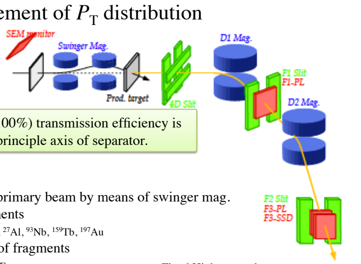


Fig. 5 HIMAC facility at NIRS

B. Measurement of P_T distribution



Constant (~100%) transmission efficiency is expected at principle axis of separator.

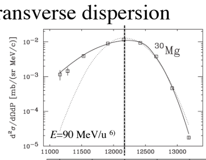
- Deflection of primary beam by means of swinger mag.
- Prod. of fragments
  ^{40}Ar, ^{84}Kr + ^{12}C, ^{27}Al, ^{93}Nb, ^{159}Tb, ^{197}Au
- Identification of fragments
  Rigidity, TOF, dE
- Normalization
  Beam current, 100% transmission/det. eff. assumed.

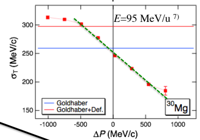
Fig. 6 High energy beam transport system (fragment separator) at HIMAC facility

4. Results

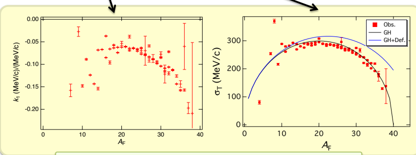
A. Correlation between transverse dispersion σ_T and P_L

- ^{40}Ar+Be@ E~100 MeV/u



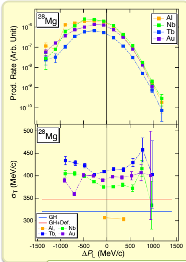


- Monotonous decreasing Fitting with linear func $\sigma_T = k_1\Delta P_L + k_0$

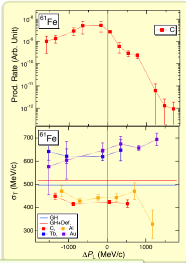


- σ_T at beam velocity is well reproduced only by Goldhaber formulation.

- ^{40}Ar+^{A}Z at 290 MeV/u

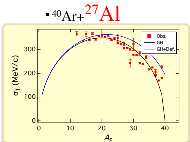


- ^{84}Kr+^{A}Z at 290 MeV/u



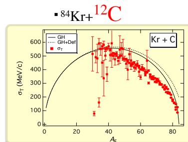
- No remarkable correlation with P_L
- Additional dispersion for heavier target

- ^{40}Ar+^{27}Al



- Same behavior with Ar+Be at 95 MeV/u

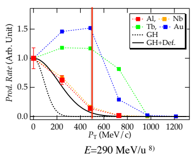
- ^{84}Kr+^{12}C



- $\sigma_T < \sigma_L$ in case of light target

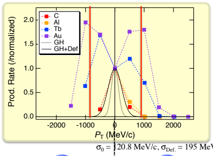
B. Orbital deflection observed in peripheral reaction : 1p-removal reaction

- ^{40}Ar+^{A}Z → ^{39}Cl [8)]

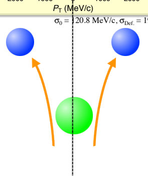


E=290 MeV/u [8)]

- ^{84}Kr+^{A}Z → ^{83}Br



σ_0 = 120.8 MeV/c, σ_{Def} = 195 MeV/c



Deflection due to Coulomb interaction between proj.(~frag.) and target

↓

Deflection effect becomes remarkable for heavy targets (Tb, Au).

Observed deflection is consistent with that corresponds to classically calculated grazing angle : θ.

Ar+Au : θ ~ 16 mrad → P_T ~ 500 MeV/c

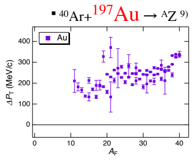
Kr+Au : θ ~ 14 mrad → P_T ~ 920 MeV/c

C. Systematics found in orbital deflection
- Evaluation of degree of orbital deflection
  Fitting by off-centered Gaussian function

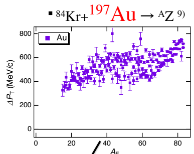
$$\frac{d\sigma}{dP_T} = k\left\{\exp\left(-\frac{(P_T - \Delta P_T)^2}{2\sigma_T^2}\right) + \exp\left(-\frac{(P_T + \Delta P_T)^2}{2\sigma_T^2}\right)\right\}$$

σ_L provided from analysis of P_L dist. is applied as σ_L in fitting process.

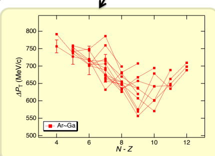
- ^{40}Ar+^{197}Au → ^{A}Z [9)]



- ^{84}Kr+^{197}Au → ^{A}Z [9)]



- Isospin dependence



The result suggests contribution of isospin.

5. Conclusions

- No remarkable correlation between orbital dispersion: σ_T and P_L at 290 MeV/u.
- In case of light target (C, Al), σ_T is well reproduced only by Goldhaber formulation.
- The remarkable orbital deflection, found in peripheral reaction with heavy target, insists dominant contribution of Coulomb interaction between proj. and target.

References
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