MOMENTUM DISTRIBUTIONS OF PROJECTILE-LIKE FRAGMENTS

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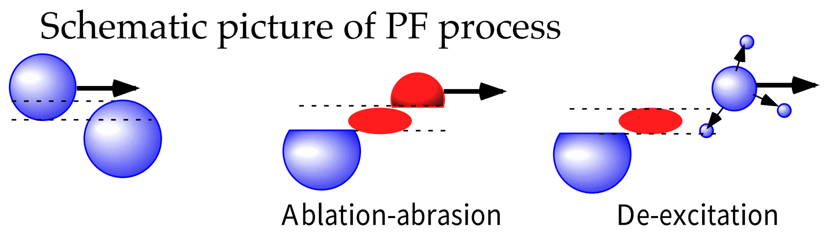
1. Purpose of this study

Projectile fragmentation (PF) process
*Powerful tool to produce RNB

Schematic picture of PF process



Systematic measurements of
A) momentum distributions and
B) production cross sections
of projectile-like fragments (PLF's)

↓

Reaction mechanism
Prediction of production rate 〉 of PLF's

2. Momentum distributions of PLF's

Momentum (P) distributions of PLF's are well reproduced by gaussian function. The previous studies have tried to understand P distribution based on following effects.

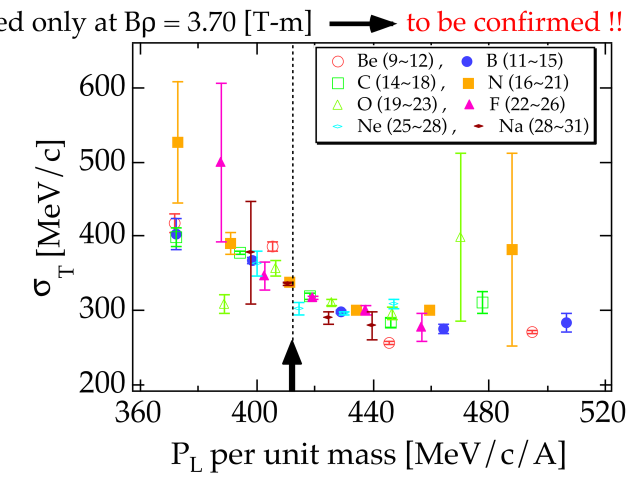
1) Fermi momentum of nucleons removed from projectile — ref. 1
2) Deflection by nuclear force of target nucleus — ref. 2
3) Deflection by Coulomb force — ref. 2

Standard deviation of P distribution

$$\sigma_T^2(A_F,Z_F) = \underbrace{\sigma_I^2}_{1)} + \underbrace{\sigma_{D\perp}^2}_{2)} \pm \underbrace{\frac{\sqrt{2\pi}}{4}(Z_P - Z_F)C_0\sigma_{D\perp}}_{4)} + \underbrace{C_0^2 (Z_P - Z_F)\left\{\frac{1}{3} + \frac{Z_P - Z_F - 1}{8}\right\}}_{3)}$$

4) : Interference between 2) and 3)

Correlation between σ_T and P_L measured at RIKEN previously (ref. 3)
measured only at Bρ = 3.70 [T-m] → to be confirmed !!



3. Production cross sections of PLF's

1) Measurements

LBL	: E_i	= 100A ~ 2000A MeV
GANIL	:	= 40A ~ 80A MeV
GSI	:	= ~ 1000A MeV
MSU	:	= 20A ~ 100A MeV

2) Empirical parametrization

Ex. EPAX2 by K. Suemmerer and B. Blank (ref. 4) etc.
Data of spallation and fragmentation at relativistic energies are utilized to determine parameters.

Target and E_i dependence are not considered sufficiently.

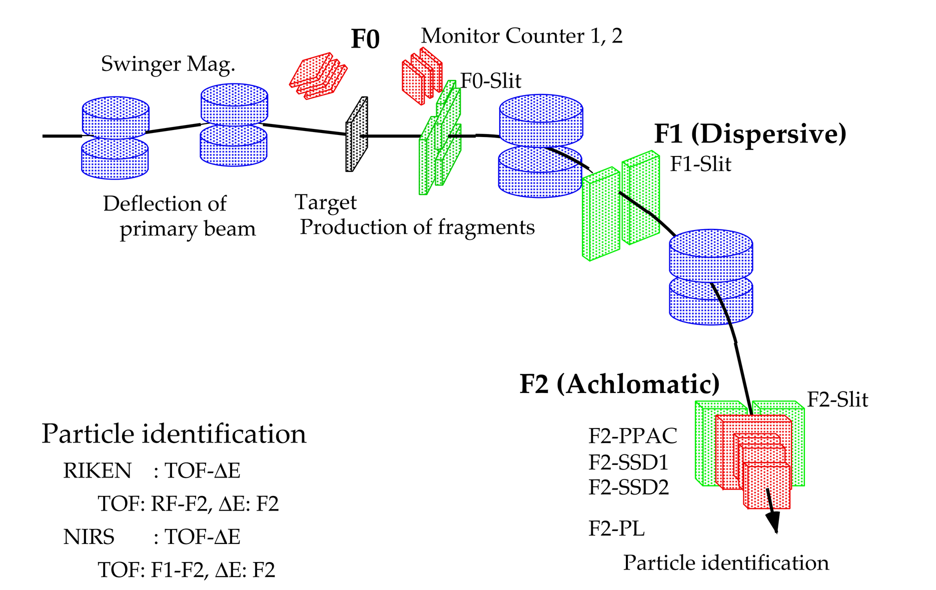
3) Model calculation

2-step calculation
Production of pre-fragment + De-excitation pre-fragment
2 types of calculation to produce pre-fragments
a. Macroscopic calculation : simple and rather valid
Ex. Statistical abrasion model etc.
b. Microscopic calculation : time consuming
Ex. AMD, QMD, Intranuclear-cascade model etc.
related to
Nuclear EOS, momentum correlation of nucleons etc.

Target dependence and Ei dependence should be measured to test and to develop above tools.

4. Experimental setup

RIPS at RIKEN.



Particle identification
RIKEN : TOF-ΔE
TOF: RF-F2, ΔE: F2
NIRS : TOF-ΔE
TOF: F1-F2, ΔE: F2

Detectors

	RIKEN	NIRS
F1-PL	-	0.5 [mmt]
F1-SSD1	350 [μmt]	325 [μmt]
F2-SSD2	350 [μmt]	-
F2-PS	1 [mmt]	1 [mm]

Measurements of momentum distributions
*P_L distribution was been measured with changing B of analyzing magnets
*P_T distribution was been measured by changing the incident angle of the primary beam deflected by the swinger magnet.

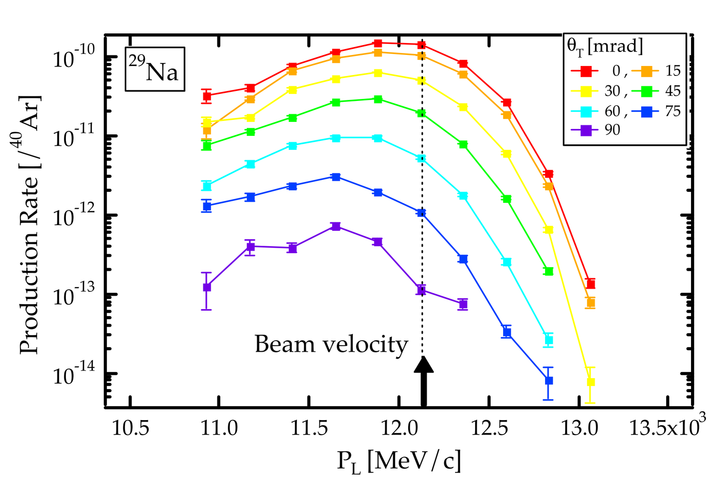
5. Experimental results

5-1. Momentum distributions at E_i = 95A MeV

Production rate of each PLF was observed as a function of P_L and P_T at RIKEN.

Reaction: ^{40}Ar (95A MeV) + ^{9}Be (0.5mmt)

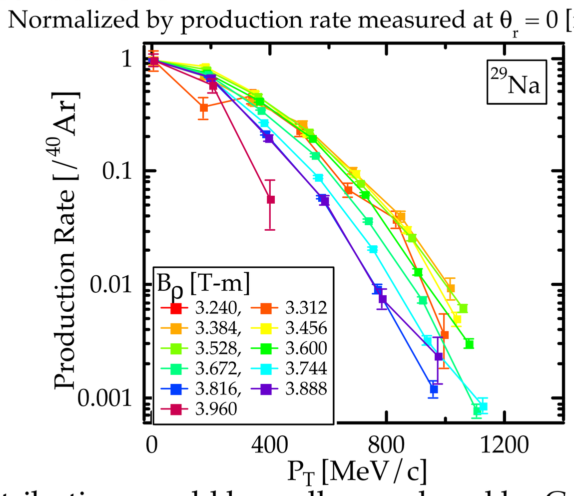
A) P_L distributions



1. The results show the typical features of P_L distribution of PLF's at intermediate energies.
   + The center of P_L distribution is close to the beam velocity.
   + The higher P_L part is Gaussian distribution and the lower part is exponential function.
2. The center of P_L distribution decreases with P_T.
3. The analysis of P_L distribution is in progress.

B) P_T distributions

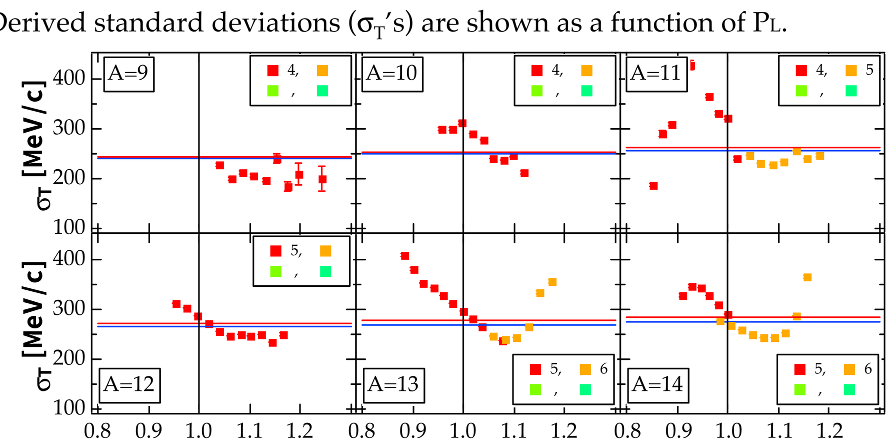
Normalized by production rate measured at θ_r = 0 [mrad]

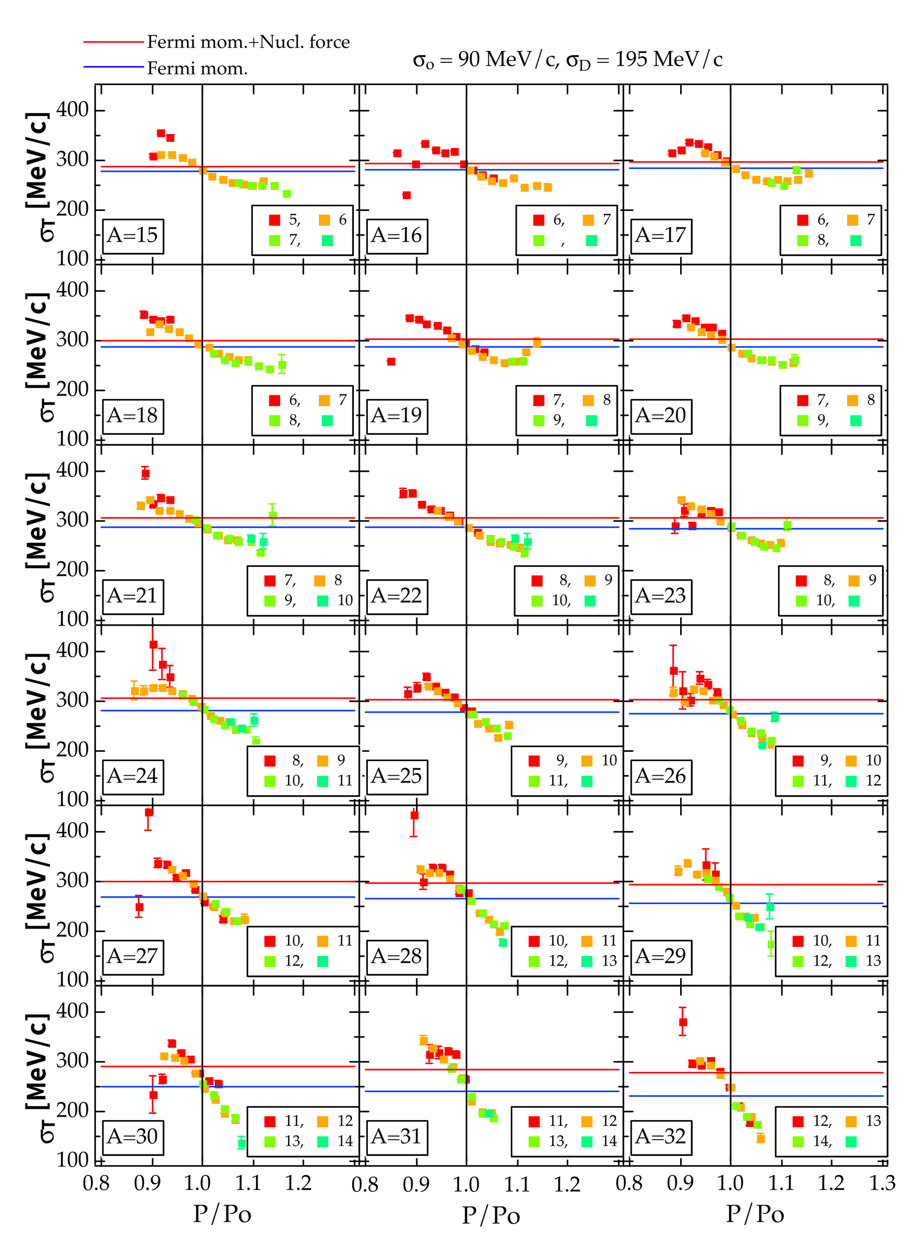


1. P_L distribution would be well reproduced by Gaussian function.
   P_L distribution will be analyzed by integrated Gaussian function.
2. The width of P_T distribution decreases with P_L.
   Correlation between standard deviation of P_T distribution (σ_T) and P_L

C) σ_T vs P_L

Observed P_T distributions were analyzed by integrated gaussian functions.
Derived standard deviations (σ_T's) are shown as a function of PL.





1. σ_T based on ref. 1 agrees with that measured at the beam velocity.
2. Correlation between σ_T and P_L.
   The correlation mentioned in ref. 3 was observed clearly. σ_T decreases with P_L of PLF. This correlation depends on mass fragment.
3. The gradient of σ_T-P_L curve becomes steeper for PLF with larger mass.
   This production mechanism of PLF will be discussed based on this systematics.

5-2. Momentum distributions at E_i = 290A MeV

Production rate of each PLF was observed as a function of P_L and P_T at NIRS.

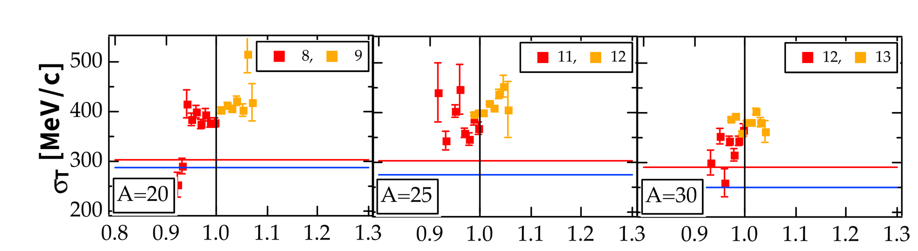
A) P_L distributions

The analysis is in progress.

B) P_T distributions

Observed P_T distributions were analyzed by integrated Gaussian function.
σ_T's derived from observed P_T distributions are shown as a function of PL.

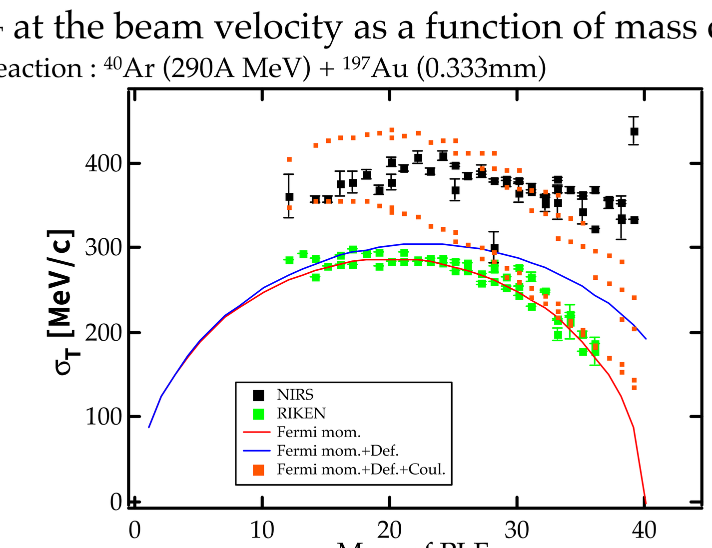
Reaction: ^{40}Ar (290A MeV) + ^{197}Ar (0.333mmt)



1. No remarkable correlations between σ_T and P_L are found.
2. σ_T is much larger than that derived from contributions of Fermi momentum and deflection.
   *Coulomb effect should be considered.

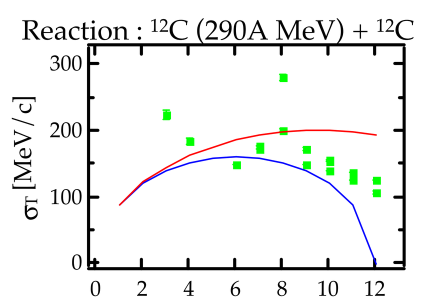
B) σ_T at the beam velocity as a function of mass of PLF

Reaction : ^{40}Ar (290A MeV) + ^{197}Au (0.333mm)



1. Correlation between σ_T and mass of PLF
2. σ_T's calculated based on ref. 2 do not reproduce observed ones.

Reaction : ^{12}C (290A MeV) + ^{12}C (1.0 mm)



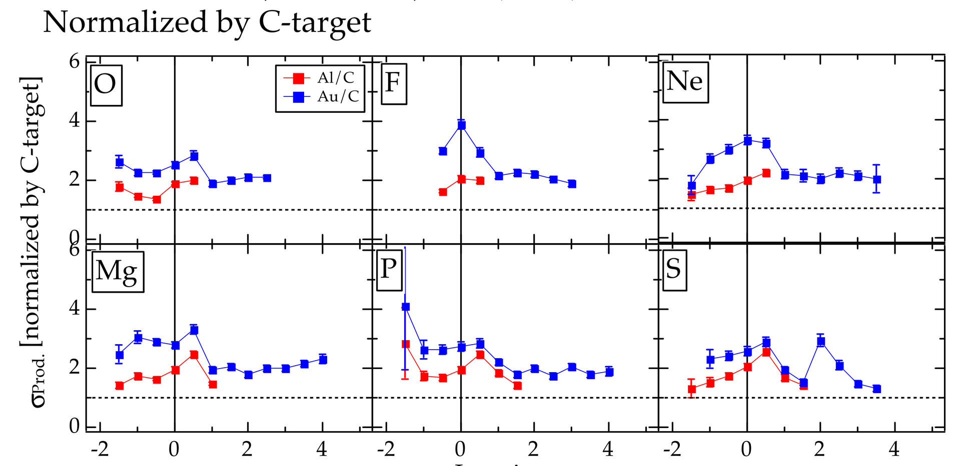
5-3. Production cross sections of PLF's

Based on the systematics of measured momentum distributions, production cross sections ($\sigma_{Prod.}$) have been derived.

Reactions: ^{12}C (290A MeV) + ^{12}C, ^{27}Al, ^{197}Au
^{12}C (430A MeV) + ^{12}C
^{14}N (290A MeV) + ^{12}C
^{16}O (290A MeV) + ^{12}C
^{40}Ar (290A MeV) + ^{12}C, ^{27}Al, ^{197}Au

A) Target dependence

Reactions: ^{40}Ar (290A MeV) + ^{12}C, ^{27}Al, ^{197}Au
Normalized by C-target

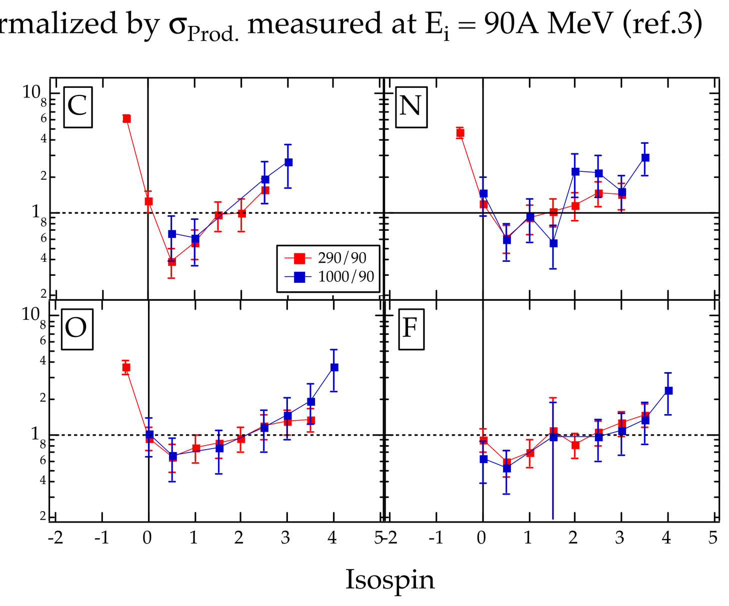


1. Productivity of PLF enhances with target mass.
   *Enhancement effect is remarkable for stable and p-rich nuclei compared with n-rich nuclei.

B) E_i dependence

Reactions : ^{40}Ar (290A MeV) + ^{12}C
: ^{40}Ar (1000A MeV) + ^{9}Be (ref.5)

Normalized by $\sigma_{Prod.}$ measured at E_i = 90A MeV (ref.3)



1. E_i = 90A -> 290A MeV
   The productivity of PLF which is close to n- and p-drip line enhances.
   +Productivity of nuclei close to the line of stability rather shrinks.
2. E_i = 290A -> 1000A MeV
   Productivity of PLF does not change.

6. Summary

1) P_L, P_T distributions and $\sigma_{Prod.}$ of PLF's produced in reactions at E_i = 95A and 290A MeV were observed systematically.

2) The correlation between σ_T and P_L at E_i = 95A MeV, which was observed previously, has been confirmed clearly.

3) P_T distributions observed with Au-target at E_i = 290A MeV were broader than that measured with lighter target. This phenomena will be understood by the contribution of Coulomb force.

4) The enhancement of productivity caused by heavier target is remarkable for PLF's which is close to the line of stability.

5) The productivity of PLF which is close to n- and p-drip line at E_i = 290A MeV is larger than that at E_i = 90A MeV.

6) The present results will help to study reaction mechanism and to predict the intensity of RNB produced by projectile fragmentation process.

ref. 1 A.S. Goldhaber, Phys. Lett. 53B (1974)306
ref. 2 K. Van Bibber et al., Phys. Rev. Lett. 43 (1979) 840
ref. 3 S. Momota et al., Nucl. Phys. A 701 (2002) 150c
ref. 4 K. Suemmerer, B. Blank, Phys. Rev. C61 (2000) 034607
ref. 5 A. Ozawa et al., Nucl. Phys. A 673 (2000) 411