Study of Projectile Fragmentation Characteristics

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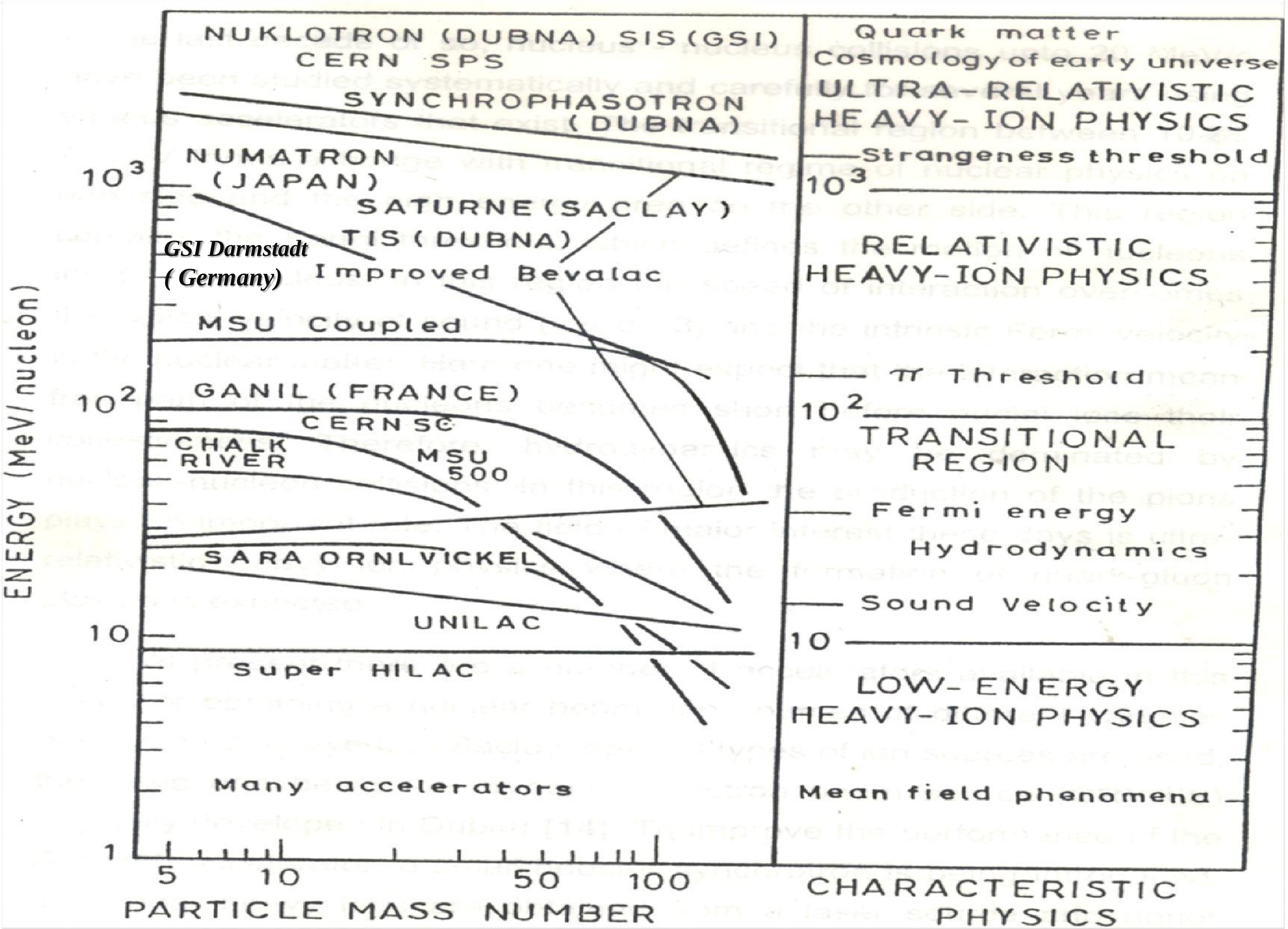
Outline

- Introduction
- Model
- Experimental Techniques
- Results
- Conclusion



Characteristic domains of the heavy ion physics

(V. Singh, PhD Thesis, 1998, BHU, India}

Emulsion Detector

1. Nuclear Emulsion is a Particle Physics Detector
2. It work as the target for interactions.
3. The information's are recorded permanently in the form of tracks.
4. It provides high angular resolution(0.25^o) and 4π solid angle coverage .
6. Highest spatial resolution i.e. < 1 µm.
7. Portable detector.

NIKFI BR-2 Nuclear emulsion photographic plate

PROJECTILE & TARGETS

Beam/Projectile	**:**	**^{84}Kr nuclei.**
Initial Kinetic energy	**:**	**~ 1 A GeV.**
Targets	**:**	**H, C ,N, O, Ag and Br.**
Exposure	**:**	**GSI (Gesellschaft fur schwerioneforschung) Darmstadt in Germany.**
Total Events	**:**	**700 Events**

Mechanism of track formation

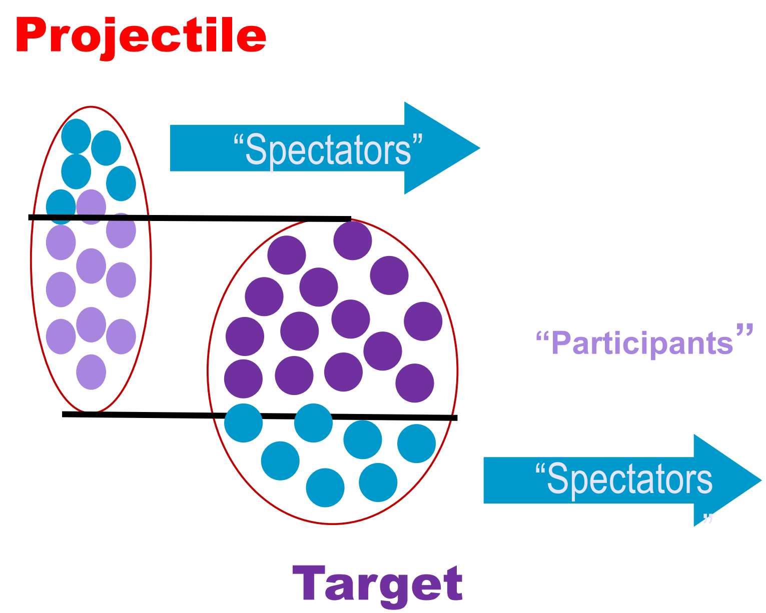
When a charged particle passes through emulsion it loses energy by electro-magnetic interactions. The energy lost by the charged particle is transferred to the atomic electrons . As a result atomic electrons are raised to excited energy states, which may result into ionization of atoms. The ionization of the atom converts some of the halide grains in such a way that when they are immersed in reducing bath, known as developer, get converted into silver grains, which may easily be distinguished because of its black color.

Participant Spectator Model

1. This model was first proposed by Knoll et al and extension of the work was done by Gyulassy et al.

J. Knoll et al., Nucl. Phys. A308, 500 (1978), M. Gyulassy et al ., Phys. Rev. Lett 40, 29 (1978)

2. All the nucleons act incoherently.
3. Straight – line motion of the projectile at high energy.
4. Overlap zone in both the nuclei.
5. The overlapping region of the colliding nuclei is called the Participant region and the rest is called Spectator region.



Fix Target Experiment

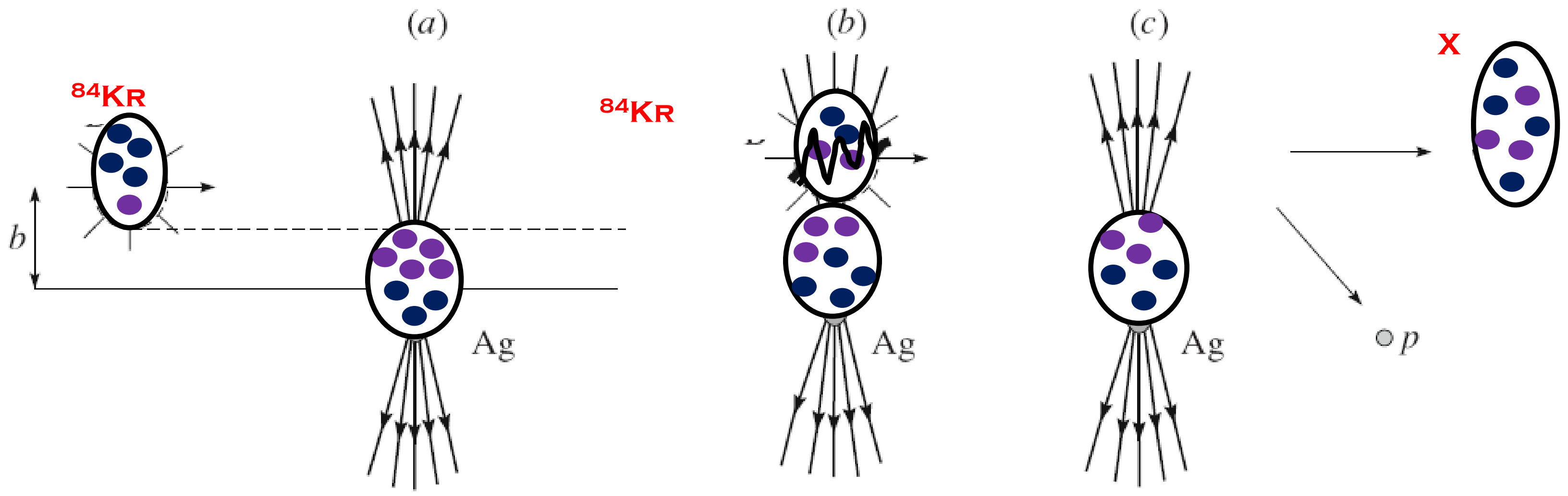
6. Multiple production of new particles like the mesons, baryons, photons, and lepton pairs are taking place from the overlapping regions.

The violent collisions happen in the participant region and in the spectator regions weak excitation and cascade collision happen.

Three interaction types were found in the experiment. They are elastic collisions, electromagnetic dissociations, and inelastic nuclear collisions.

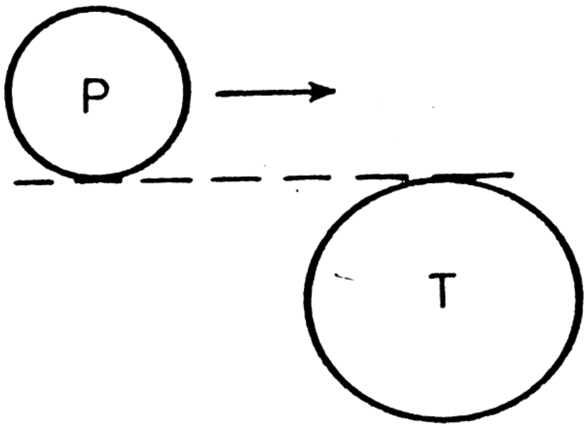
An elastic collision is an interaction occurring between the projectile and the target in the emulsion. The final state products are only the projectile (fragments) and the Target (black).

An electromagnetic dissociation is an interaction occurring between the projectile and the target due to electromagnetic interactions. The final state product contain the projectile fragments or the target fragments.

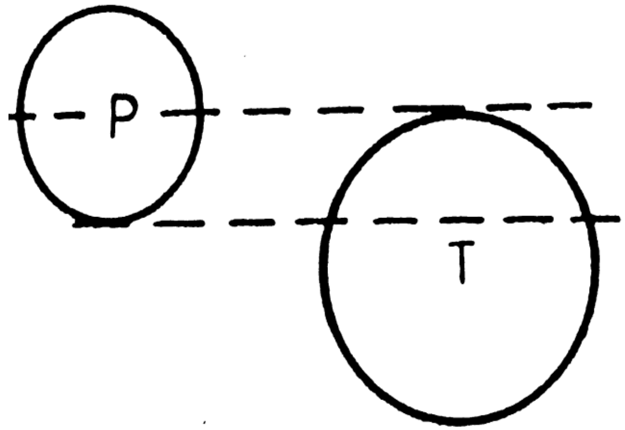


A inelastic collision is an interaction occurring between the two colliding nuclei due to nuclear interactions. The final state products contain the projectile fragments, the target fragments, the relativistic produced particles, and a few slow mesons.

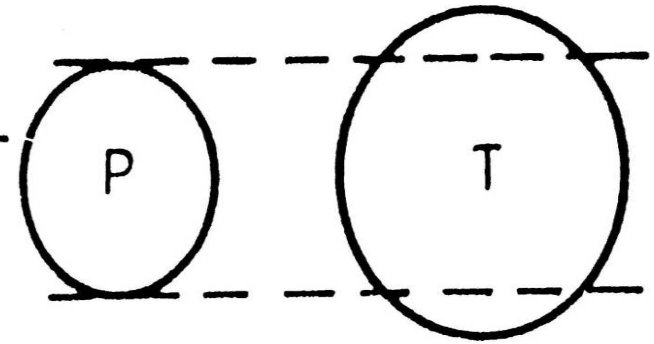
Collision Geometry



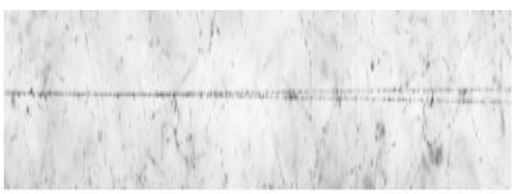
$b \approx |R_P + R_T|$



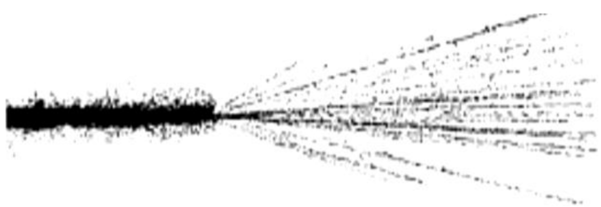
$|R_P + R_T| > b \geq |R_P + R_T$



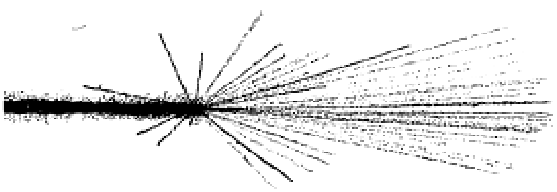
$0 \leq b < |R_P + R_T|$



Peripheral collision



Quasi – central collision



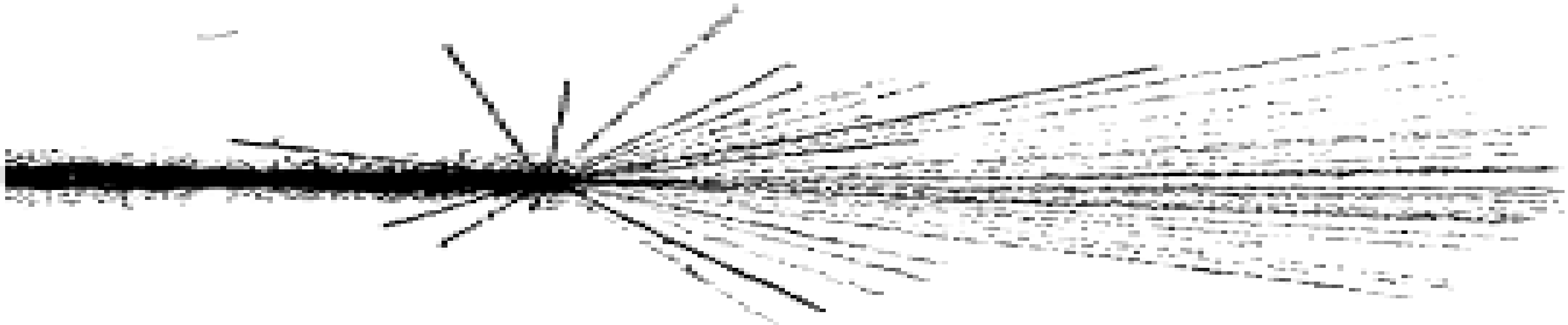
Central collision

1- In Peripheral collision only small momentum is transferred between the interacting nuclei during collision.

2- In quasi-central and central collisions the number of nucleons taking part in the reaction is large compared to that in case of peripheral collisions.

3- In central collision almost complete destruction of both projectile and target nuclei with large amount of energy and transverse momentum, transferred from the projectile to target nucleon in the high density and high temperature region.

Classification of tracks



All secondary charged particles produced in an interaction are classified in accordance with their ionization, range and velocity into the following categories

Shower particle (N_s): The fragments having g*≤1.4 and $\beta \geq 0.7$. It is single charge relativistic particles , with energy above than 70 MeV, contaminated with small fraction of fast proton with energies above than 400MeV.

Grey particle (N_g): The fragments having 1.4< g* <6.8 and $0.3 \leq \beta < 0.7$ and range L>3mm, these are associated with recoiling proton of the target in energy range 30-400 MeV.

Black particle (N_b): The fragments having g* ≥ 6.8 and $\beta \leq 0.3$ and L ≤ 3mm ,emitted from excited target nuclei, with energy range 30 MeV.

Heavily ionizing charged particle *(N_h)* is the sum of N_b and N_g and also called the target nucleus.

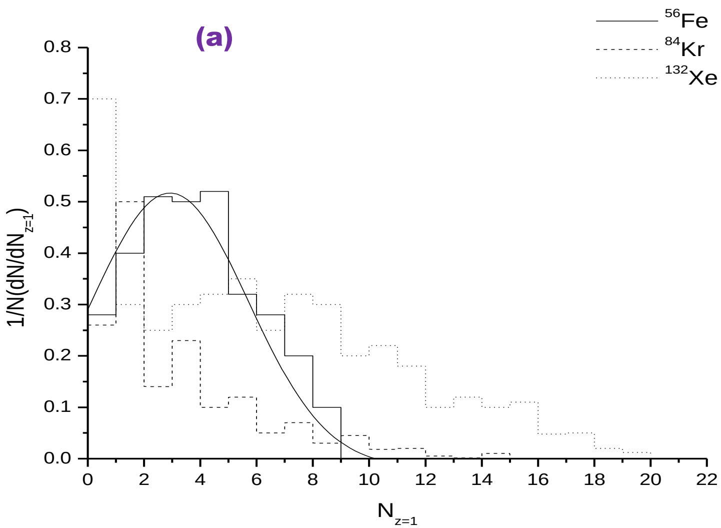
Projectile Fragments: *projectile fragments are the spectator parts of the projectile nucleus.*

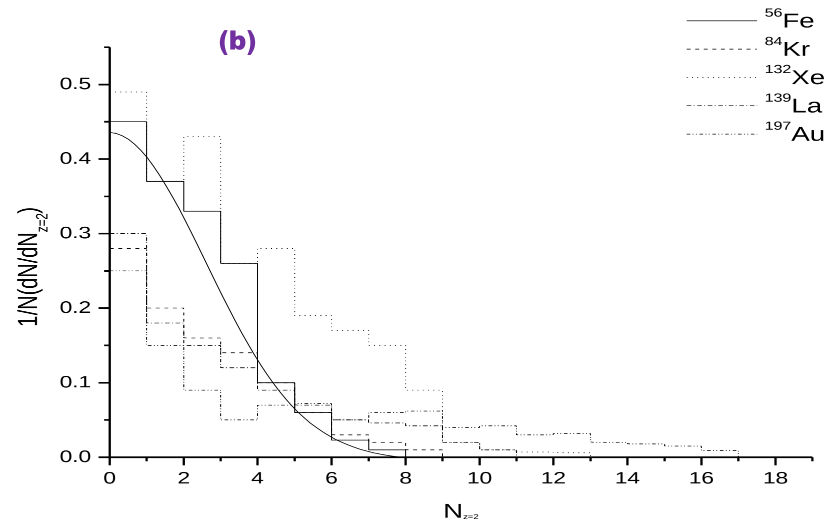
Singly charged projectile fragments ($N_{z=1}$): These projectile fragments having velocity closed to the beam velocity.

Alpha Projectile Fragments (N_{α}); These projectile fragments having charge z=2. It can be distinct from single charge PFs , because ionization is directly proportional to Z^{2}.

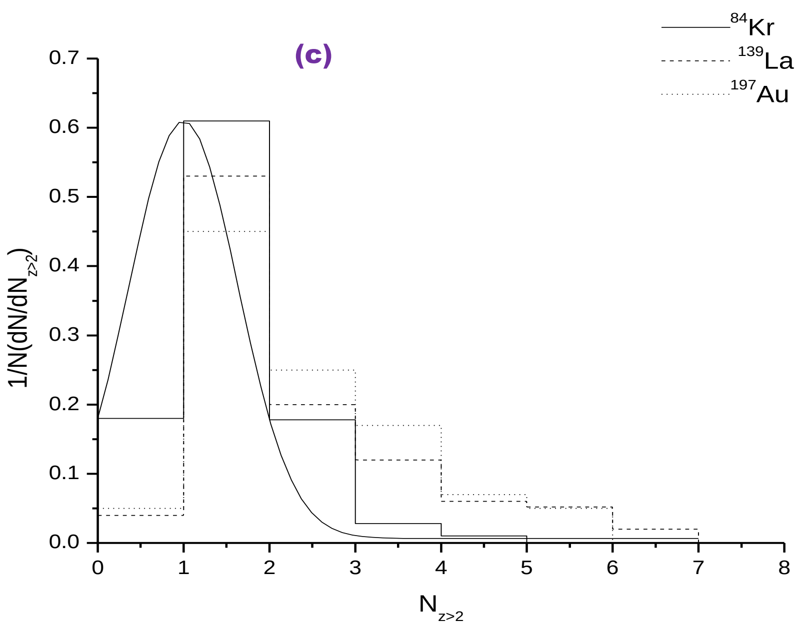
Heavy Projectile fragments (N_f): At relativistic energies, multiple charged fragments are emitted from the breakup of the projectiles essentially travel with the same speed of the beam. These projectile fragments having charge $z \geq 3$.

Multiplicity distribution of Projectile fragments



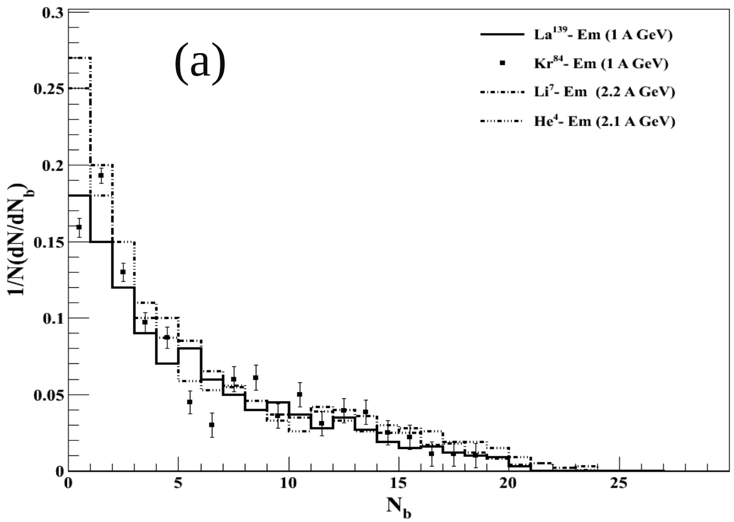


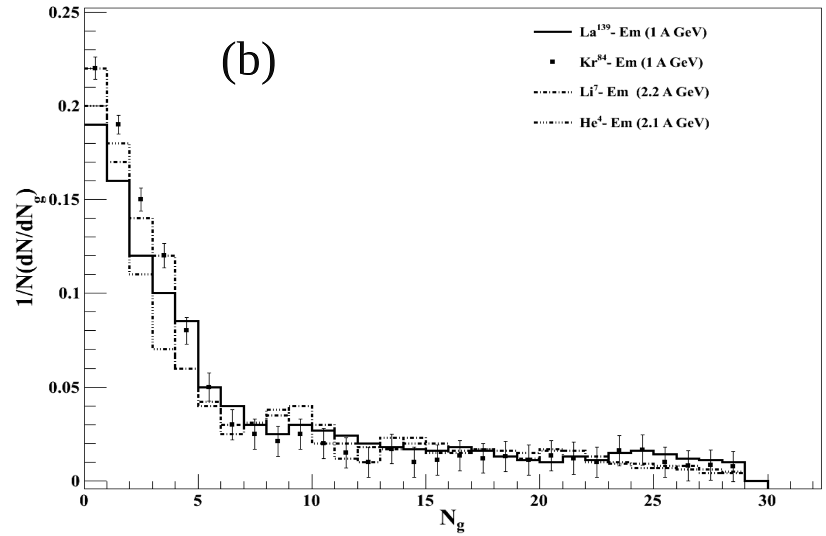
Frequency distribution of the (a) Singly (b) Double (c) Multiple charged PFs in nucleus interactions with Emulsion



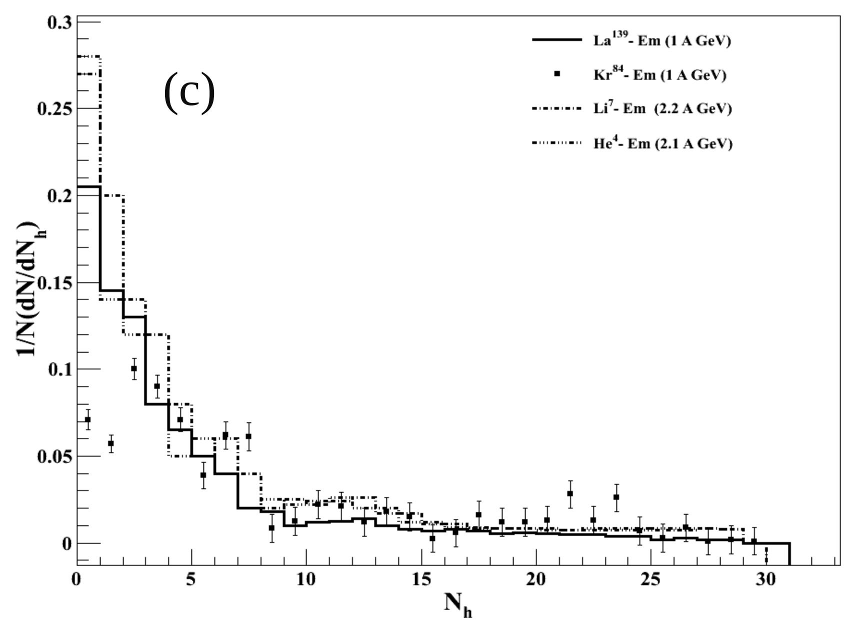
Interactions	Energy (AGeV)	$\langle N_f \rangle_{z\geq3}$	$\langle N_f \rangle_{z=2}$	$\langle N_f \rangle_{z=1}$
^{40}Ar+Em	1.1	0.83+0.03	1.37+0.22	1.96+0.08
^{84}Kr+Em	0.95	1.1+0.04	1.86+0.06	3.00+0.27
^{139} La+Em	1.2	1.79+0.09	2.39+0.12	-----------
^{197} Au +Em	1	2.30+0.08	5.22+0.20	-----------

Multiplicity distribution of Target

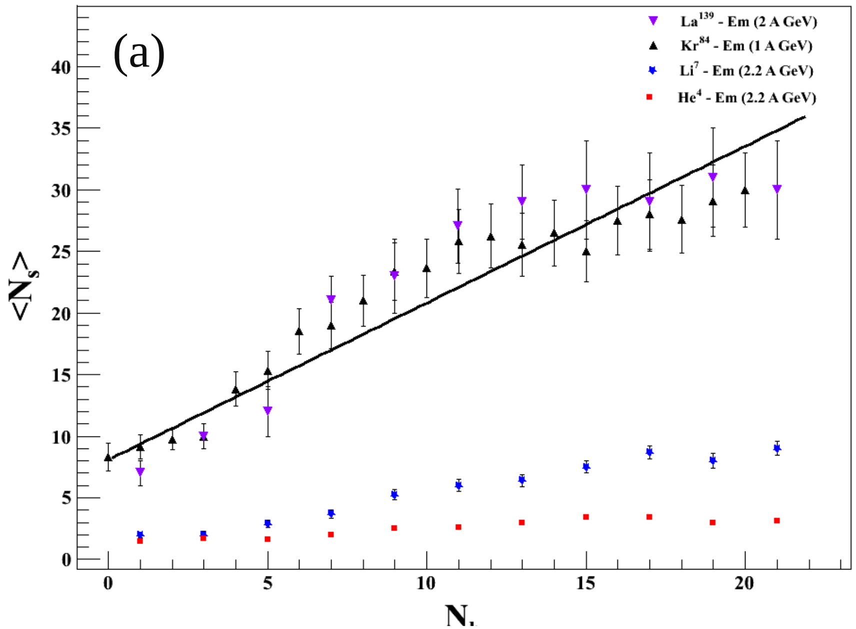


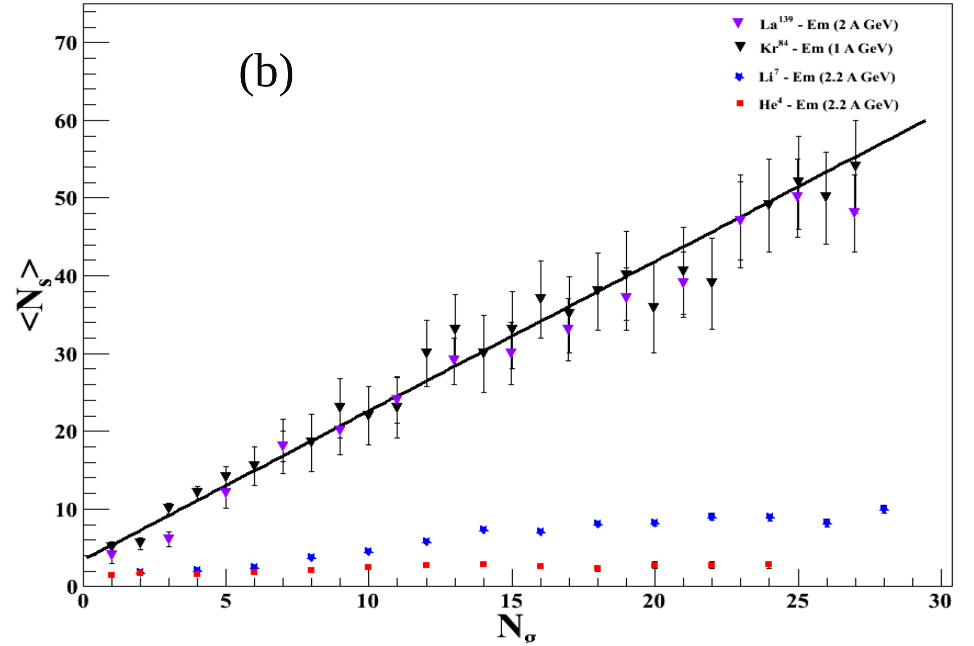


Normalized multiplicity distribution of **(a)** black, **(b)** grey, **(c)** heavily ionizing particles for different projectile at nearly same energy.

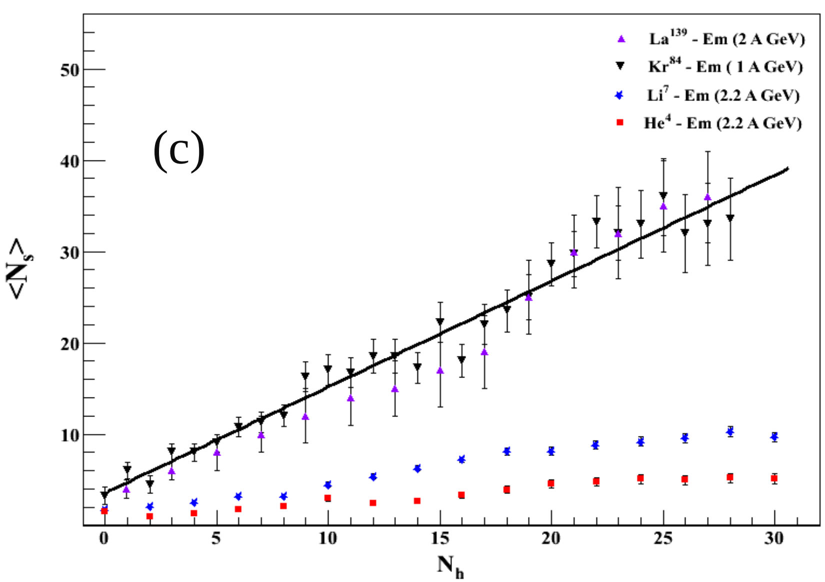


Fragmentation Correlation

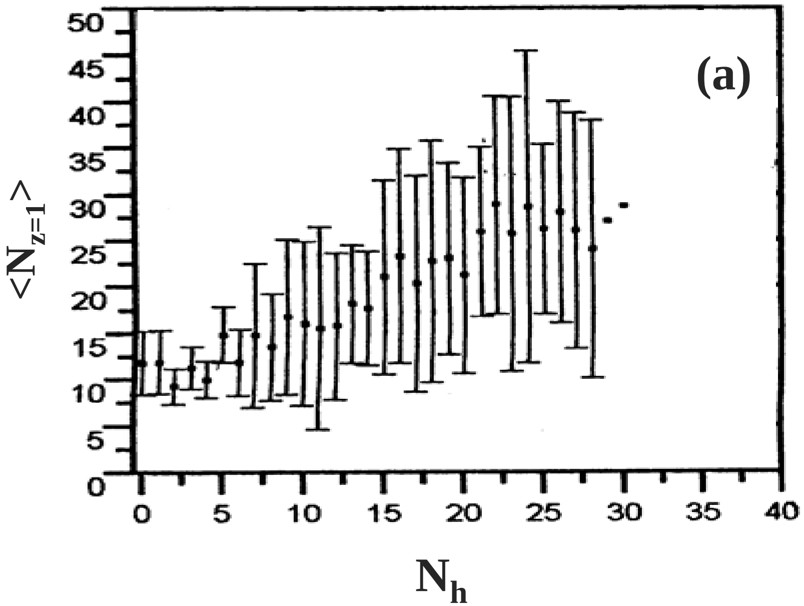


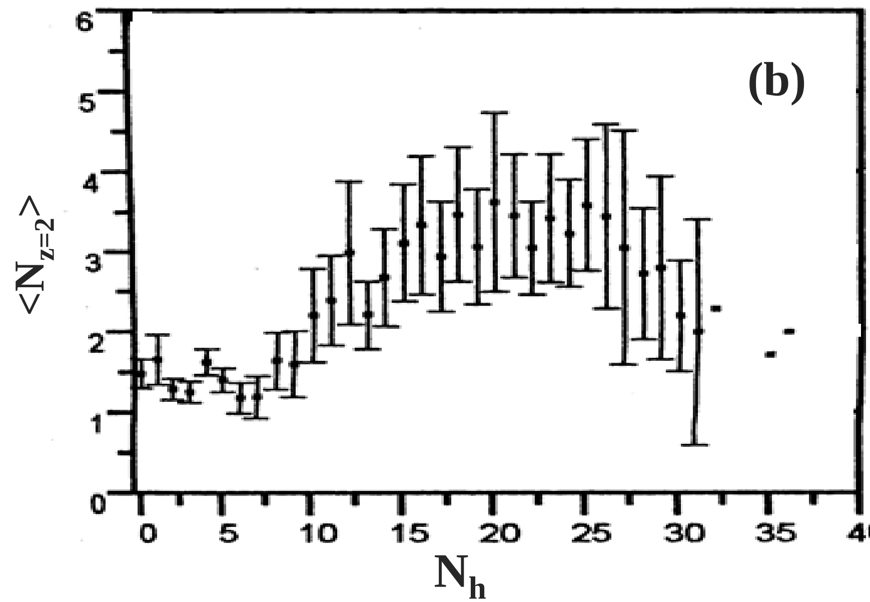


The Correlation between $<N_s>$ as a function of (a) N_b , (b) N_g , and (c) N_h , for different projectile at nearly same energy.

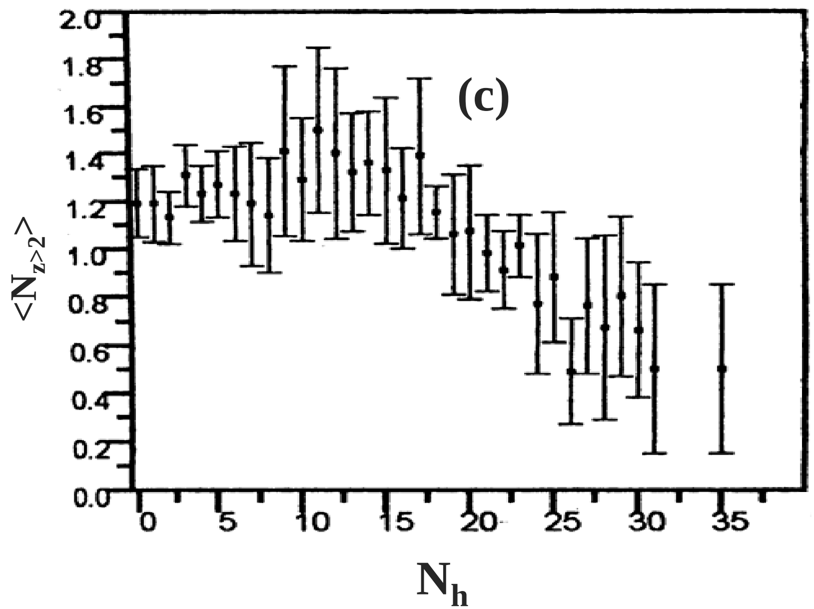


S.N.	Fitting Value	N_s_Vs_N_b	N_s_Vs_N_g	N_s_Vs_N_h
[a] La^{139}	P_0	5.998 ± 0.798	1.768 ± 0.756	2.388 ± 0.756
	P_1	1.519 ± 0.114	1.897 ± 0.089	1.168 ± 0.089
Kr^{84}	P_0	8.095 ± 0.508	3.418 ± 0.465	3.576 ± 0.418
	P_1	1.272 ± 0.068	1.920 ± 0.077	1.160 ± 0.043
[b] Li^{7}	P_0	1.321 ± 0.176	0.849 ± 0.103	1.451 ± 0.085
	P_1	0.387 ± 0.019	0.364 ± 0.009	0.318 ± 0.008
[c] He^{4}	P_0	1.339 ± 0.068	1.439 ± 0.097	0.948 ± 0.086
	P_1	0.105 ± 0.007	0.079 ± 0.012	0.149 ± 0.008





Multiplicity Correlation (a) <$N_{z=1}$>, (b) <$N_{z=2}$> and (c) <$N_{z>2}$> on N_h

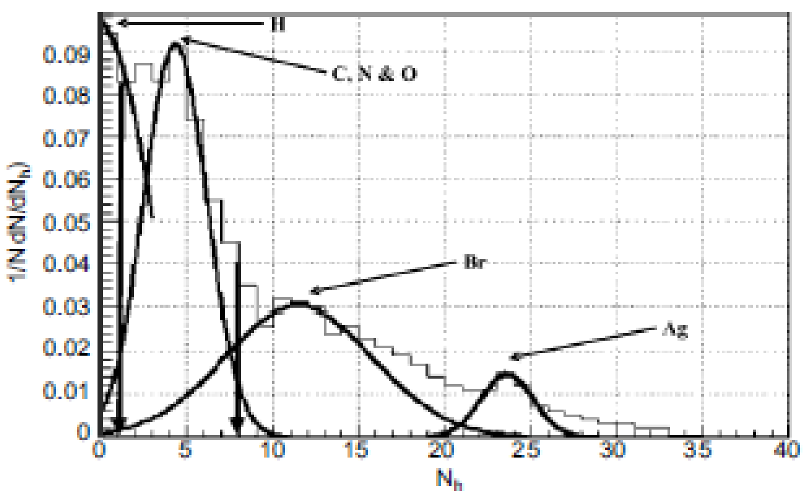


Target Separation

AgBr Target Events : $N_h \geq 8$ and at least one track with $R < 10\mu m$ is present in an event. This class of target can make further separation between Ag and Br target interaction with high enough accuracy. That interactions having Nh>21 will be of the Ag-target class with small fraction of Br-target event.

CNO Target Events : $2 \leq N_h \geq 8$ and no tracks with $R < 10\mu m$ are present in an event. This class always contains very clean interaction of CNO target.

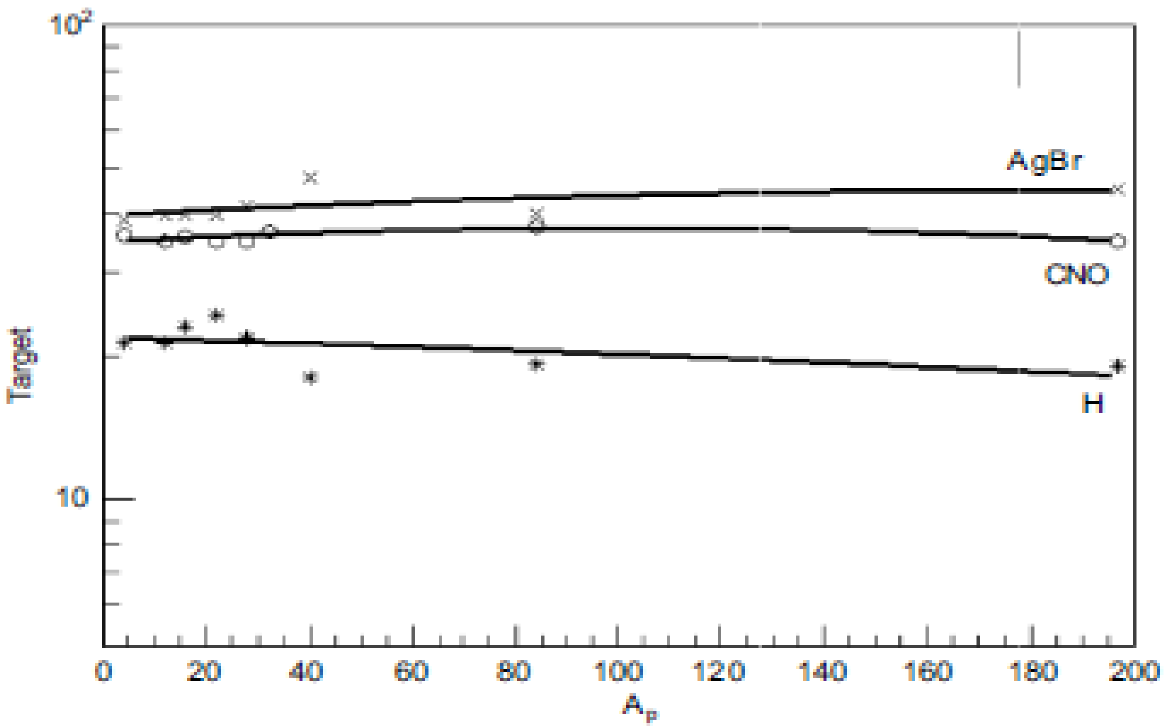
H Target Events : $N_h \leq 1$ and no tracks with $R < 10\mu m$ are present in an event. This class includes all 84Kr+H interactions but also some of the peripheral interactions with CNO and very peripheral interactions with Ag/Br targets.



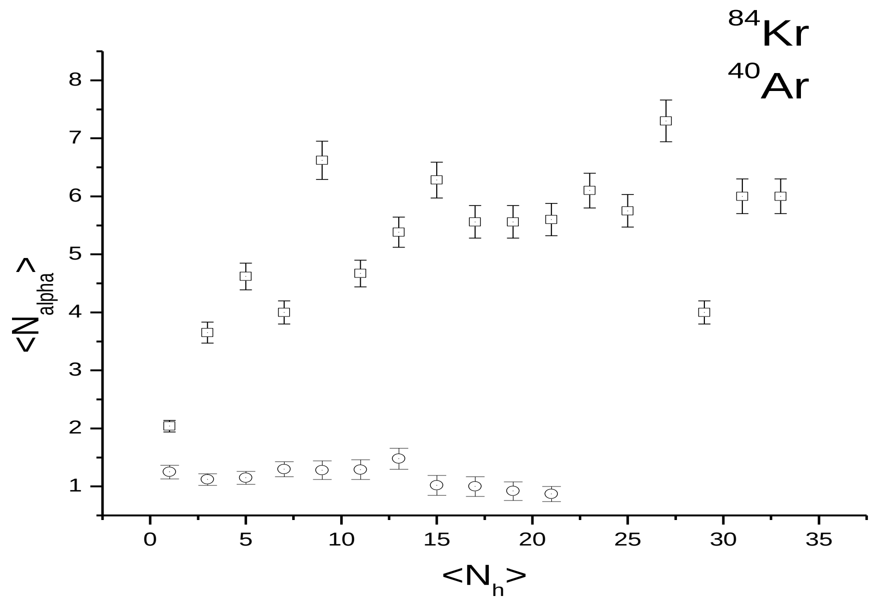
Normalized heavily ionizing charged particle multiplicity distribution.

M K Singh et al., Indian J. Phys. 84(9) 1257-1273 (2010).

- On the basis of the above criteria we obtained 13.4, 39.0 and 47.6 percent of interactions with H, CNO and Ag/Br targets respectively.
- In principle, the percentage of target interactions with incident projectile should depend on the projectile mass number and its energy Due to the change in cross-section.
- H-target shows weak dependence with projectile mass number, while other target groups are almost independent due to the admixture of the different centrality events of other target groups.



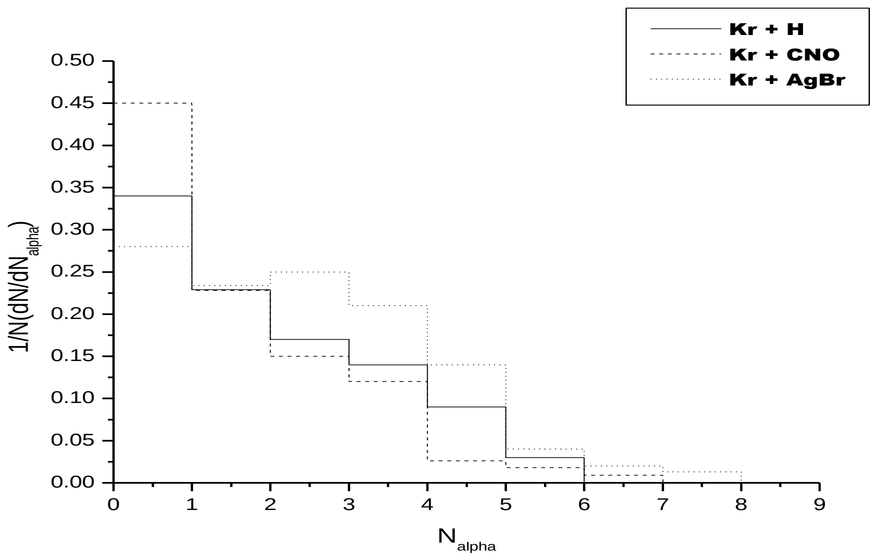
Percentage of target interactions as a function of projectile mass number



Average number of alphas<N_α> as a function of <N_h>

Projectile	Energy AGeV	0	1	2	3	4	5	6
^{14}N	2.1	63 ± 3	21 ± 1	10 ± 1	6 ± 2			
^{16}O	2	35 ± 4	20 ± 2	22 ± 3	20 ± 2	3 ± 2		
^{40}Ar	1.8	41 ± 2	31 ± 1	17 ± 1	7 ± 1	3 ± 1	1 ± 1	
^{56}Fe	1.8	22 ± 1	27 ± 1	21 ± 1	15 ± 1	9 ± 1	4 ± 1	2 ± 1
^{84}Kr	1.0	25 ± 2	20 ± 1	24 ± 1	17 ± 1	10 ± 1	3 ± 1	2 ± 1

Percentage occurrence of N_α Events



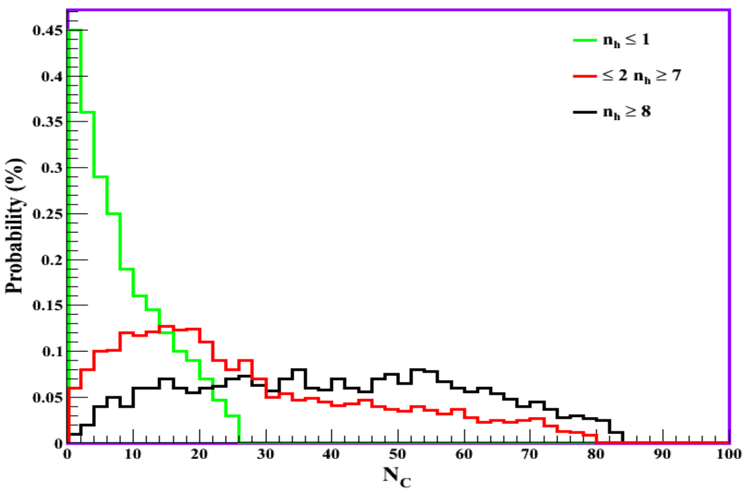
Projectile	Energy AGeV	H	CNO	AgBr
^{14}N	2.1	12.7 ± 1.2	32.9 ± 2.0	**54 ± 3.0**
^{16}O	2.0	10.8 ± 2.0	37.9 ± 6.0	**51.3**
^{40}Ar	1.8	17.8 ± 1.5	34.6 ± 1.8	**47.5 ± 3.0**
^{56}Fe	1.8	16.6 ± 0.8	35.6 ± 1.8	**47.8 ± 2.6**
^{84}Kr	**1.0**	**13.3 ± 0.8**	**39.0 ± 2.2**	**47.6 ± 2.7**

Percentage occurrence of interaction with different targets

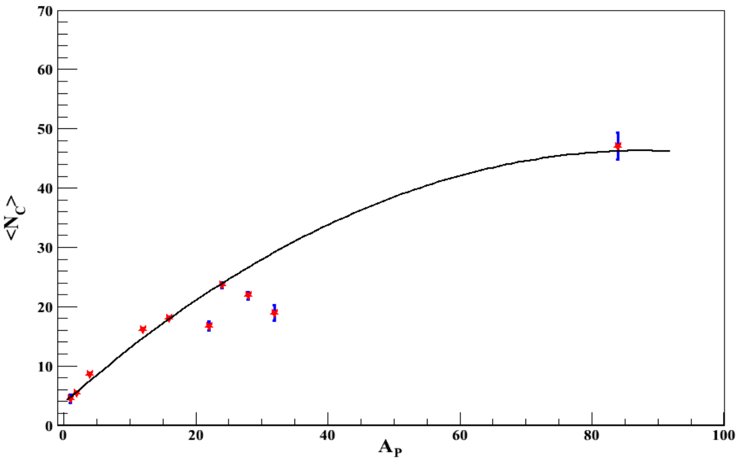
Multiplicity distributions of He fragments, with target groups

Compound Multiplicity Characteristics

✓ The concept of the Compound multiplicity ($N_c = N_s + N_g$) was introduced by authors *(Ghosh et al., Indian Acad. Science., 73 (2009))* in the case of hadrons-nucleus interactions.

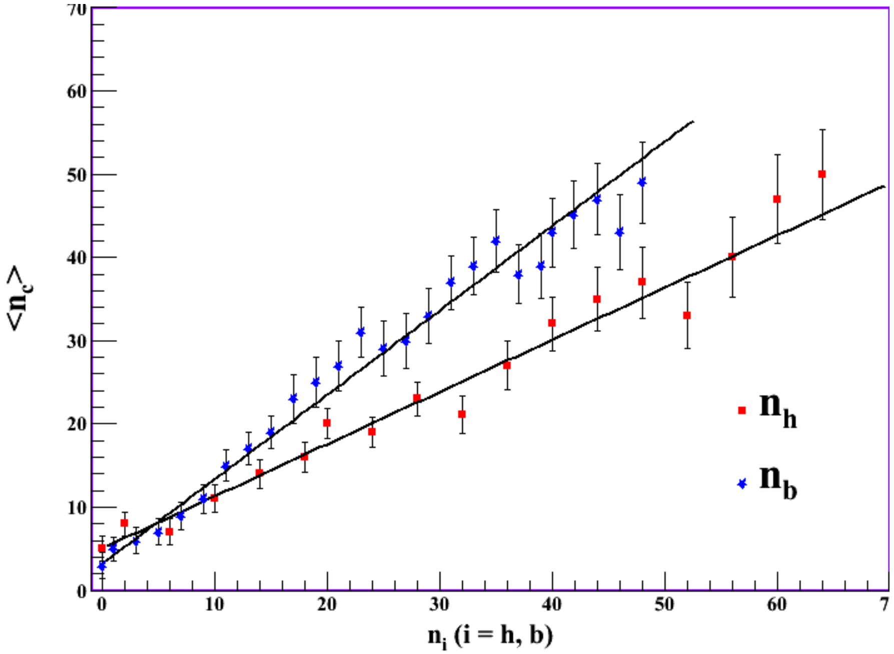


Compound multiplicity distributions for different groups of N_h.

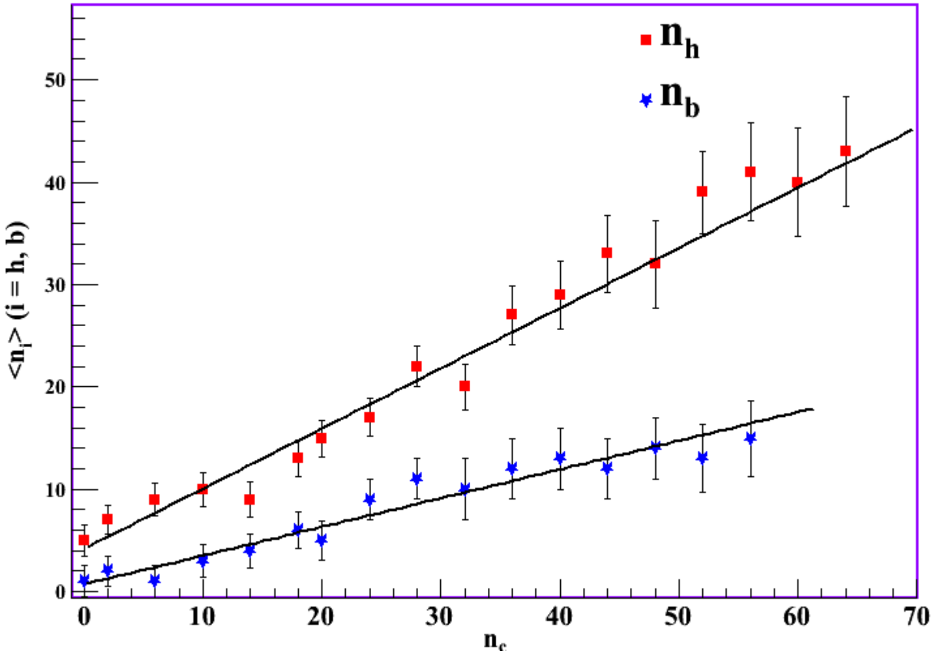


Dependence of $<N_c>$ on the mass of the projectiles.

Target group	$<n_c>$	$D(n_c) = \sqrt{<n_c^2> - <n_c>^2}$	$<n_c>/D(n_c)$
H	7.56 ± 0.12	4.47 ± 0.32	1.69 ± 0.37
CNO	14.93 ± 0.15	10.66 ± 0.28	1.40 ± 0.53
Emulsion	47.04 ± 0.27	27.19 ± 0.40	1.73 ± 0.67
Ag/Br	53.27 ± 0.31	20.10 ± 0.79	2.65 ± 0.39



Dependence of $<n_c>$ on n_i(i= h, b) for ^{84}Kr with emulsion at around 1 AGeV.



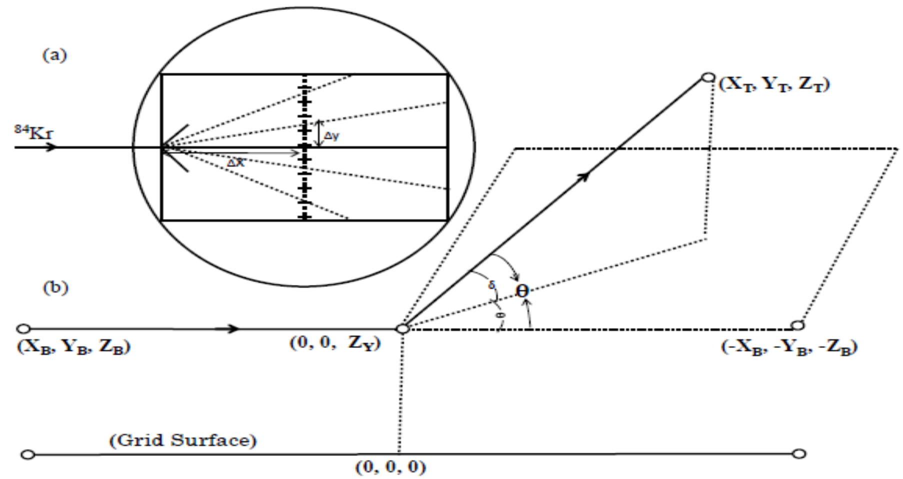
Dependence of n_i(i= h, b) on $<n_c>$for ^{84}Kr with emulsion at around 1 AGeV.

- It can be seen that $<n_c>$ increases linearly with increasing n_b and n_h.
- It is observed that the value of inclination coefficient are strongly depends on the projectile mass.

Angular measurement

The angle of emission of different particles is determined by finding the space angle of the corresponding track with primary beam. Since space angle cannot be determined directly, its value is obtained by following relations

$$\theta_s = \mathrm{Cos}^{-1}(\mathrm{Cos}\,\theta_p \times \mathrm{Cos}\,\theta_d)$$



Where θ_p and θ_d are projected and dip angles respectively, of a particular track and defined by the following relations

$$\theta_p = \tan^{-1}(\Delta Y / \Delta X)$$

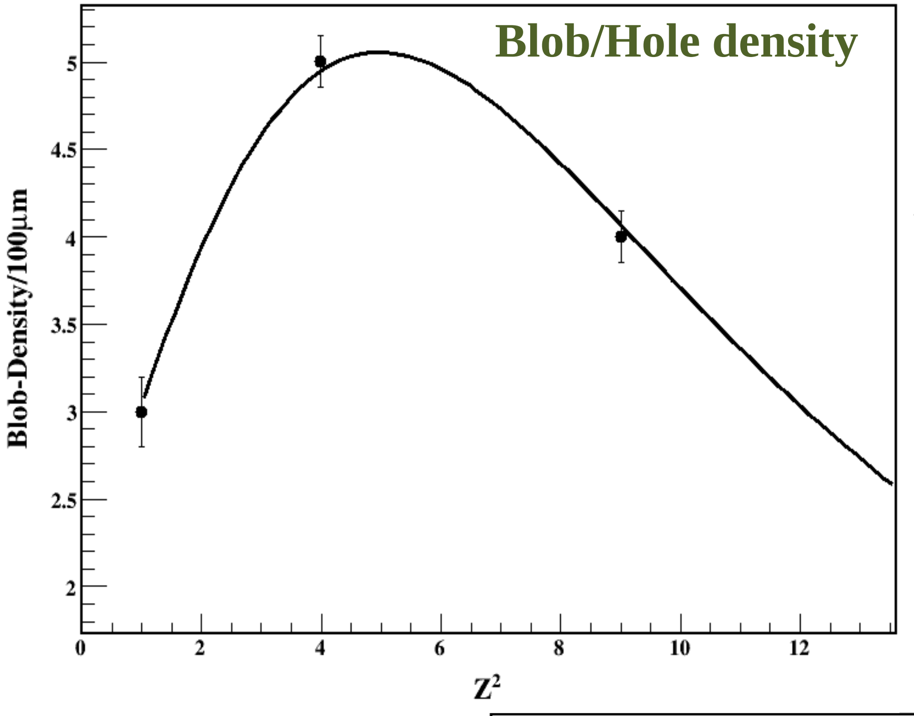
$$\theta_d = \tan^{-1}[(\Delta Z \times S.F.)/(X^2+Y^2)^{1/2})]$$

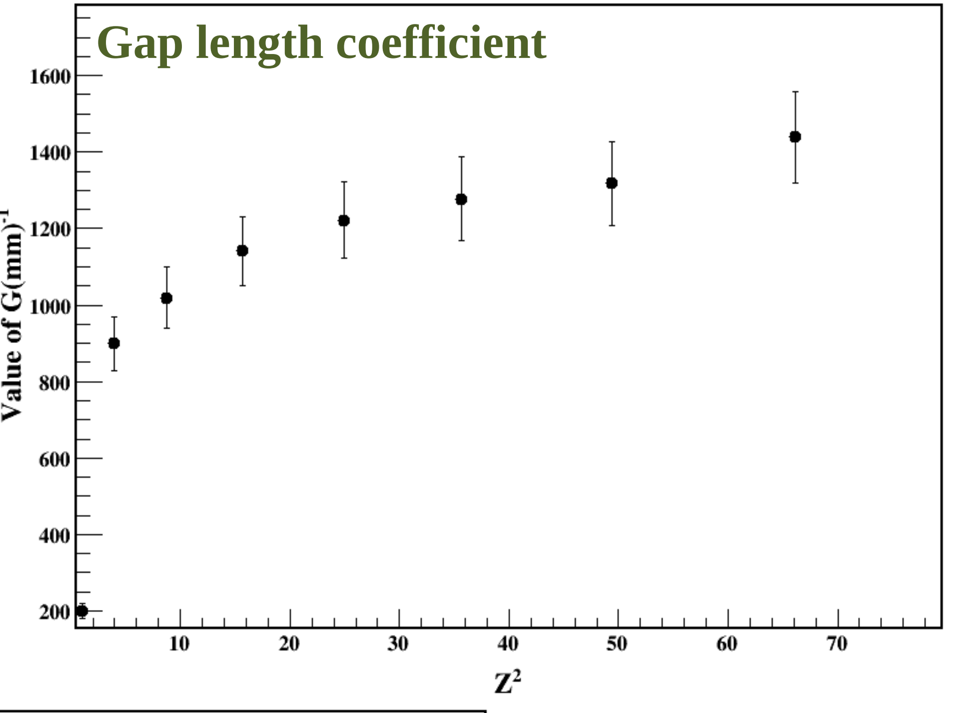
Where Δz is the change in Z coordinate in a distance x and y in the (x - y) plane.
S is the shrinkage factor.

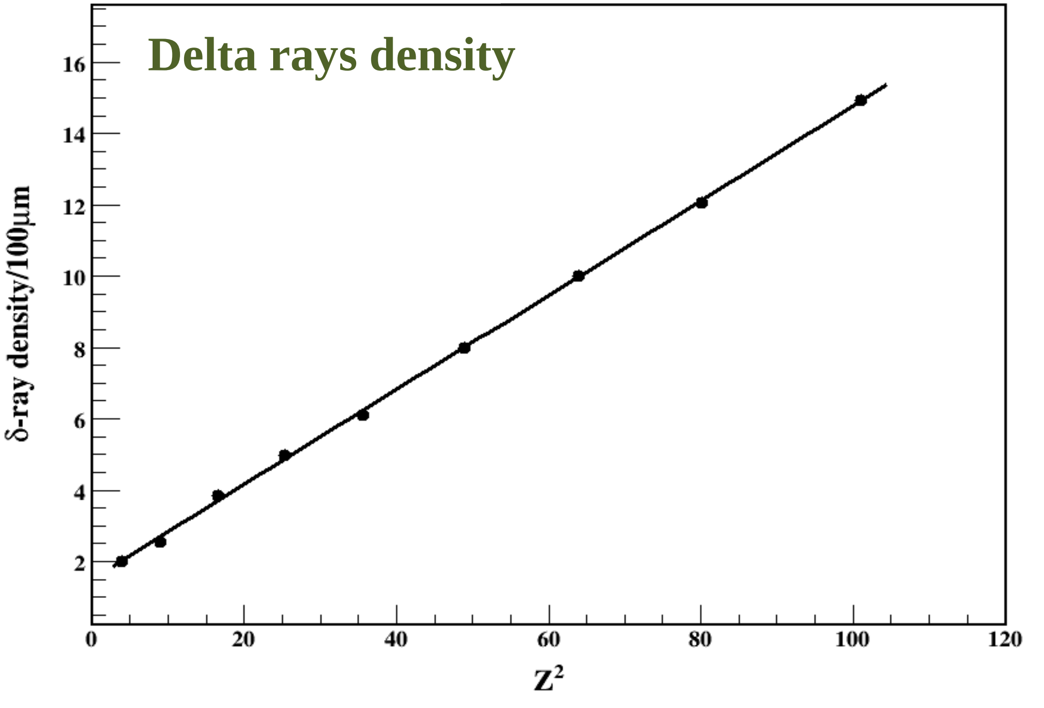
Charge Measurement

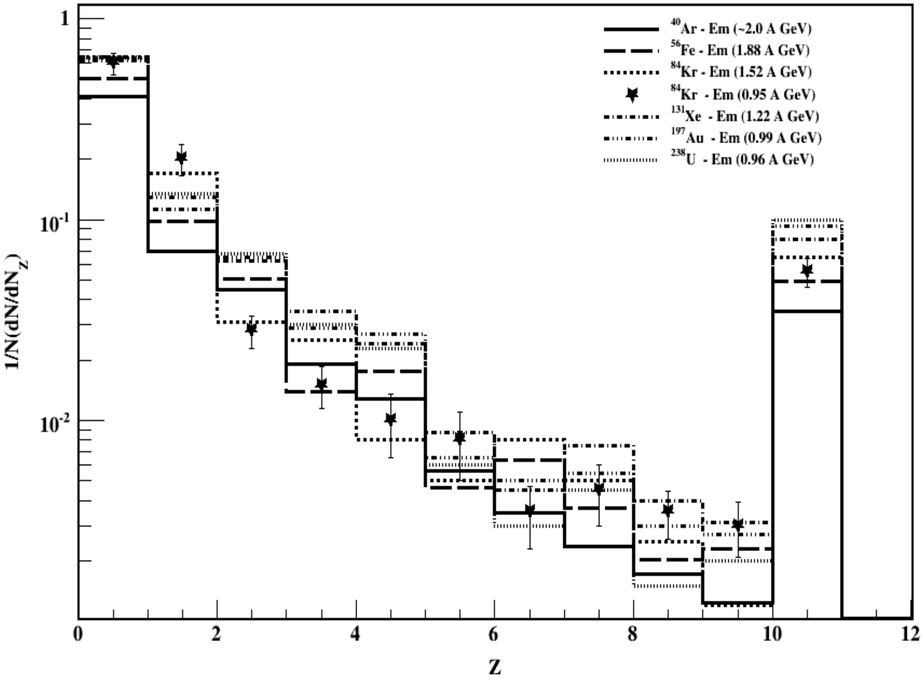
A single method can not be applied to estimate the charge over entire range Because each method has its own limitations.

- Blob/Hole density : charge of projectile fragments ($Z \leq 4$).
- Gap length coefficient : charge of projectile fragments ($4 < Z \leq 9$).
- Delta rays density : fragments having charge($10 < Z < 19$).
- Relative track width : fragments having charge $Z > 19$.

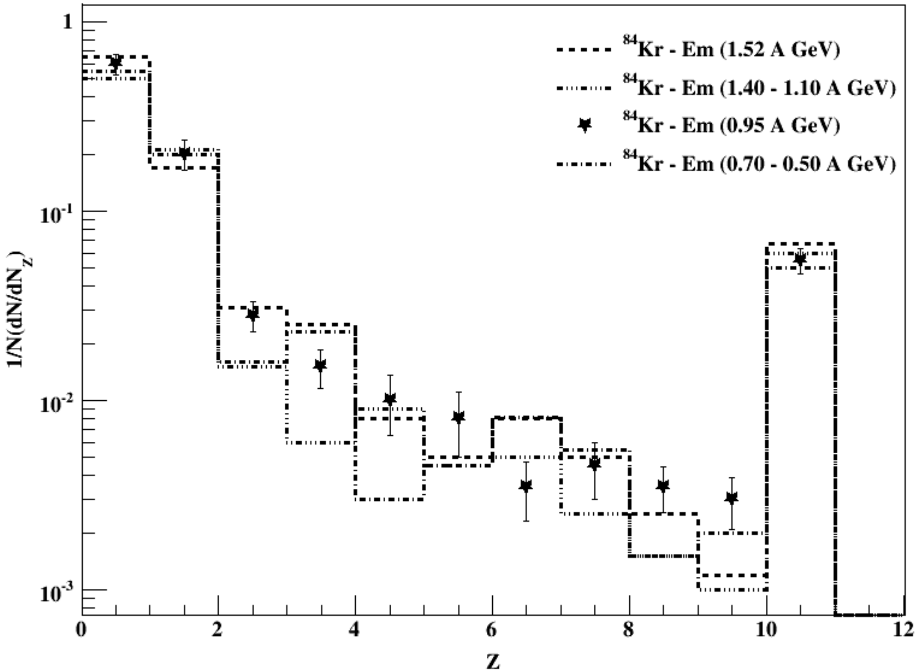

Blob/Hole density
Blob-Density/100µm
Z²


Gap length coefficient
Value of G(mm)⁻¹
Z²


Delta rays density
δ-ray density/100µm
Z²

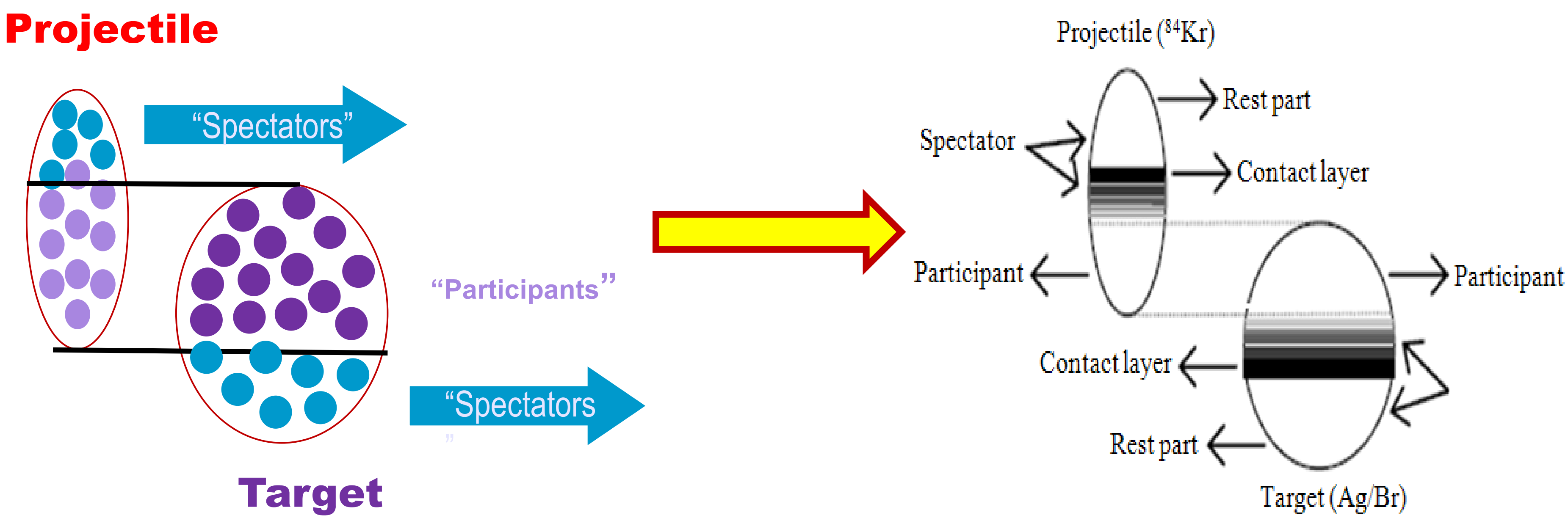


Different projectile at similar energy



Same projectile at different energy.

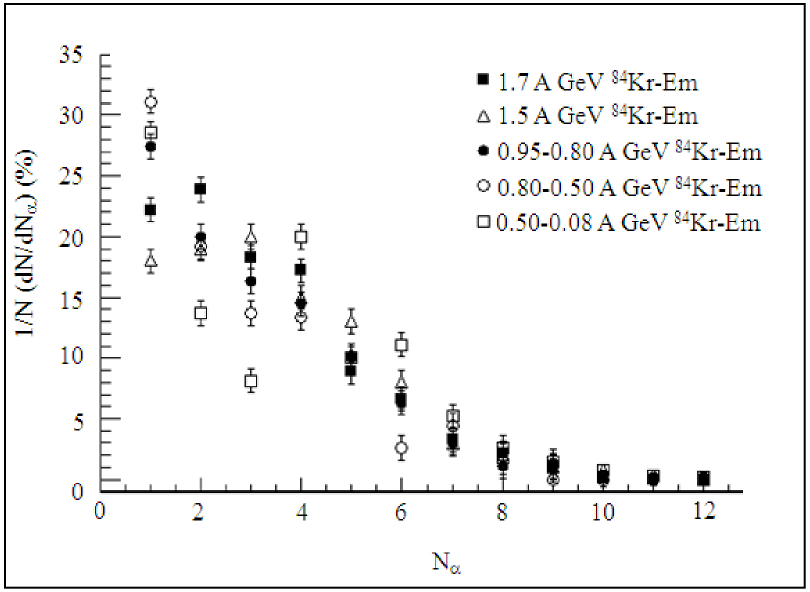
Modified PS Model

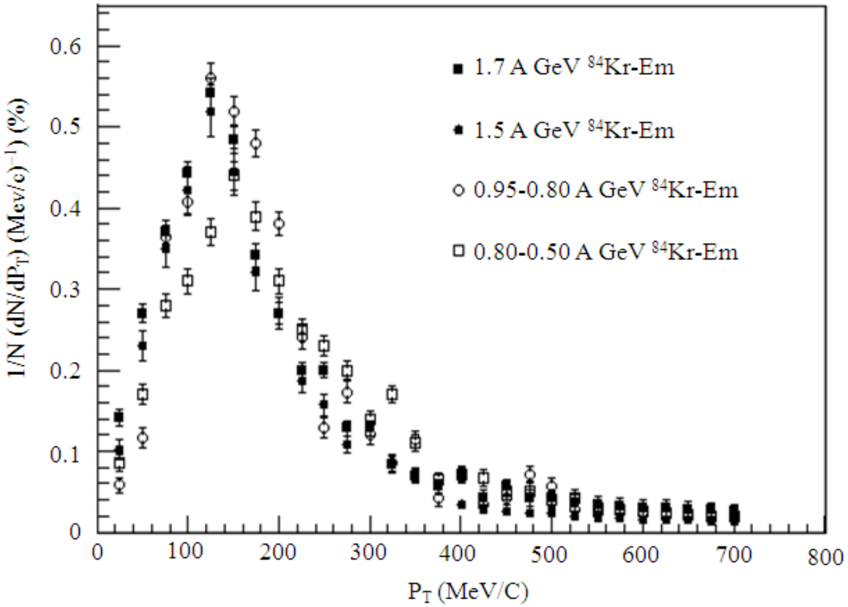


$$P_{pt}(p_T) = \frac{p_T}{\sigma_p^2} \exp\left(\frac{-p_T^2}{2\sigma_p^2}\right).$$

$$P_{pT}(p_T) = \left(\frac{A_H p_T}{\sigma_H^2}\right)\exp\left(\frac{-p_T^2}{2\sigma_H^2}\right) + \left(\frac{A_L p_T}{\sigma_L^2}\right)\exp\left(\frac{-p_T^2}{2\sigma_L^2}\right)$$

M. K. Singh et al., Physics International 1(2): 109-115, (2010).





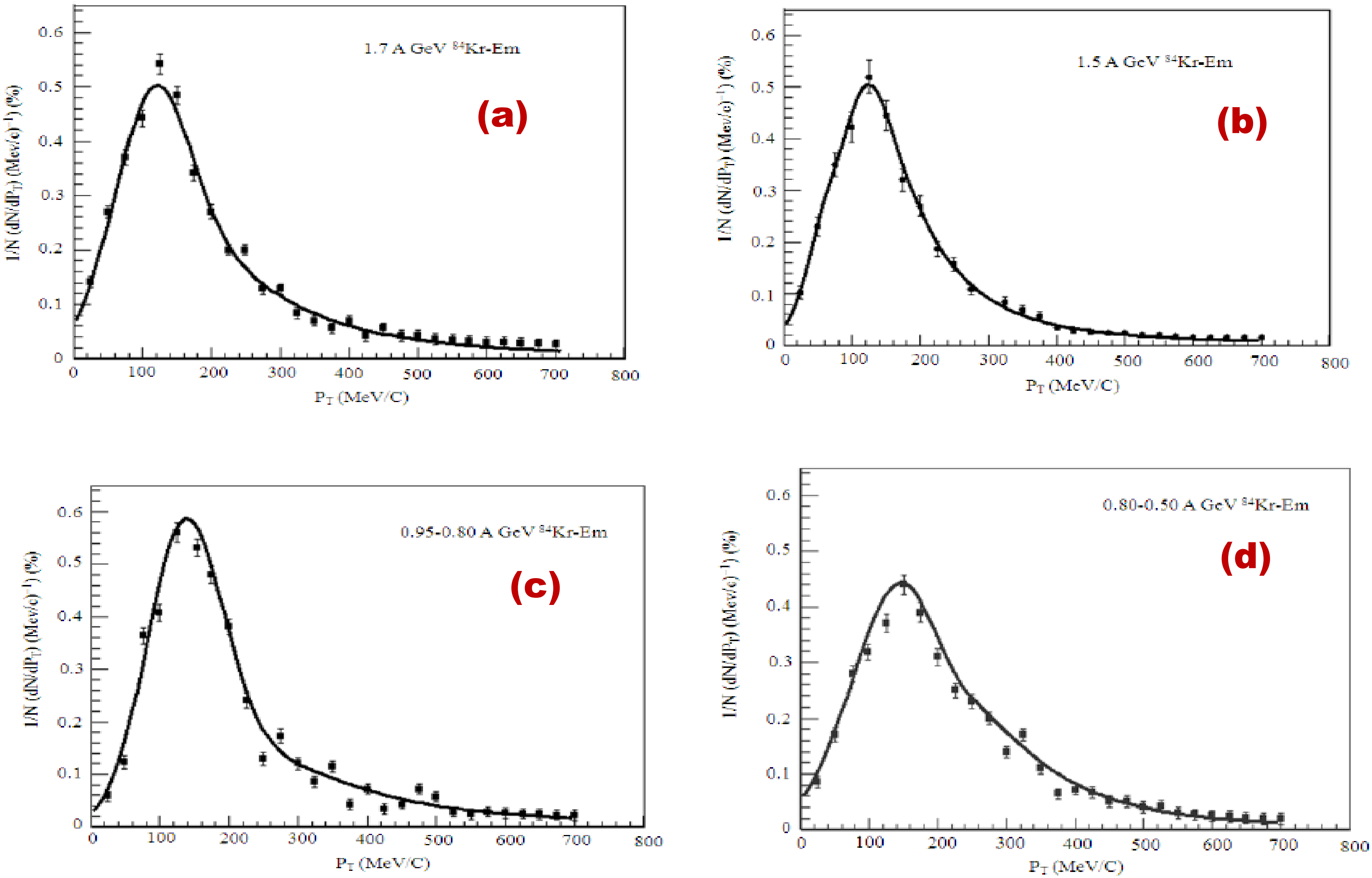
Multiplicity distribution of helium PFs

Transverse momentum distribution of helium PFs

$$P_T = A_F P_0 \sin\theta$$

P_0 = momentum of the incident projectile

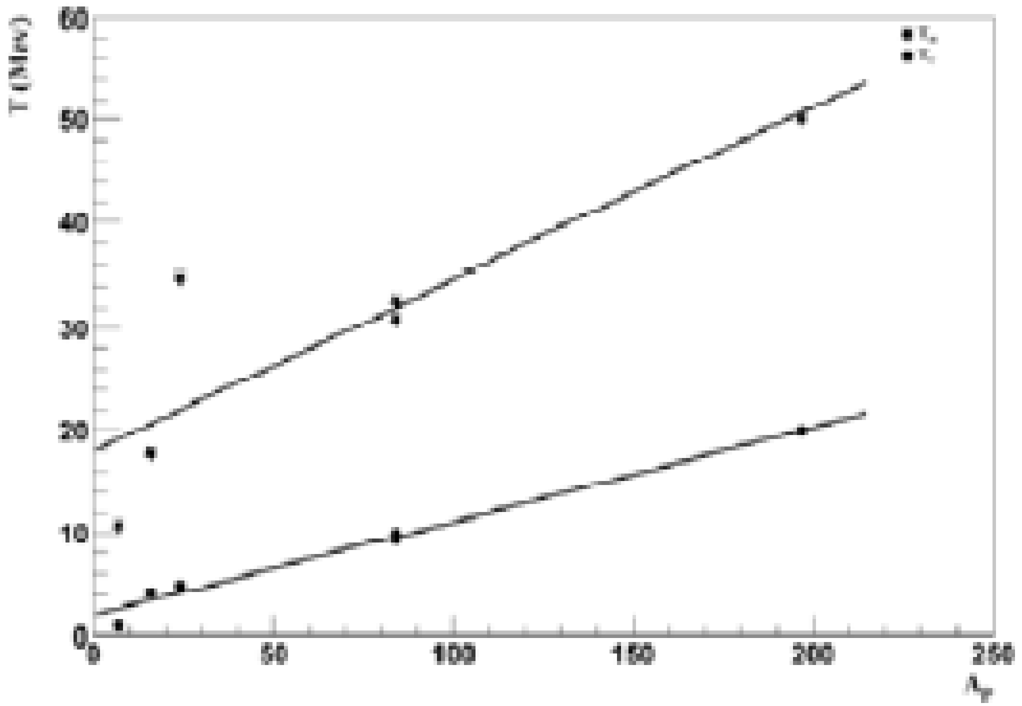
θ = Emission angle of the fragments w.r.t. the projectile direction



Transverse momentum distribution of helium PF's at different energies.
Closed circle are observed value and solid curve is the calculated values from the assumption.

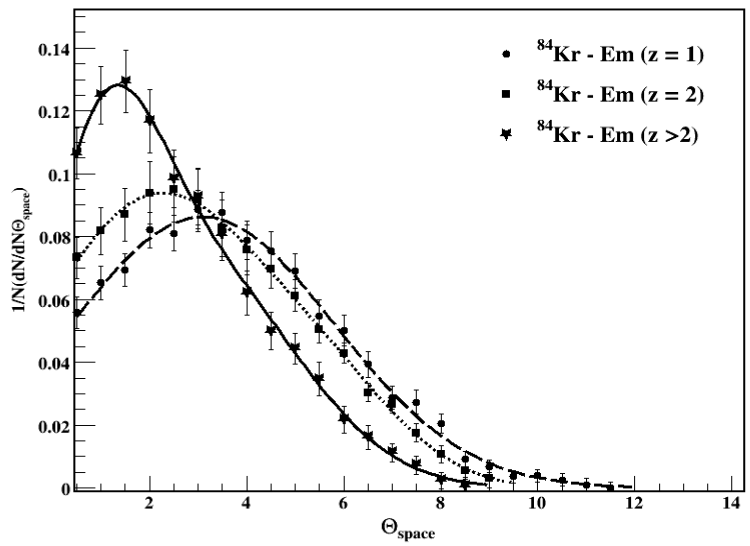
Rayleigh scattering function's fitting parameters

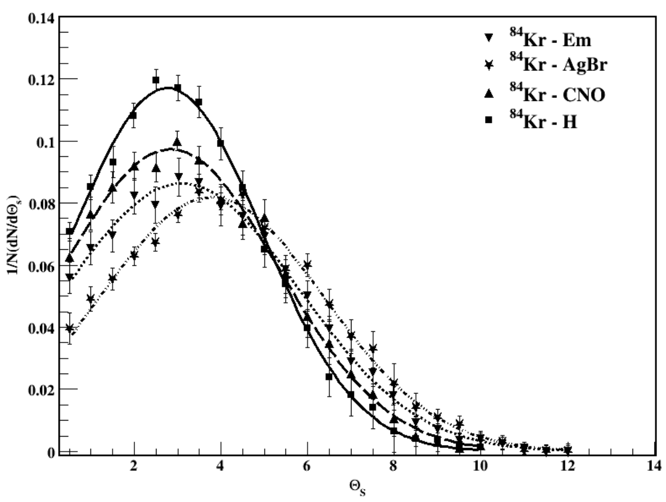
Projectile	Energy (A GeV)	A_H	A_L	σ_H (MeV/c)	T_H (MeV)	σ_L (MeV/c)	T_L (MeV)
^{84}Kr	1.7	0.5	0.5	175	32.64	96	9.82
^{84}Kr	1.5	0.5	0.5	172	31.53	95	9.62
^{84}Kr	0.95-0.80	0.5	0.5	170	30.80	93	9.22
^{84}Kr	0.80-0.50	0.5	0.5	169	30.44	92	9.02

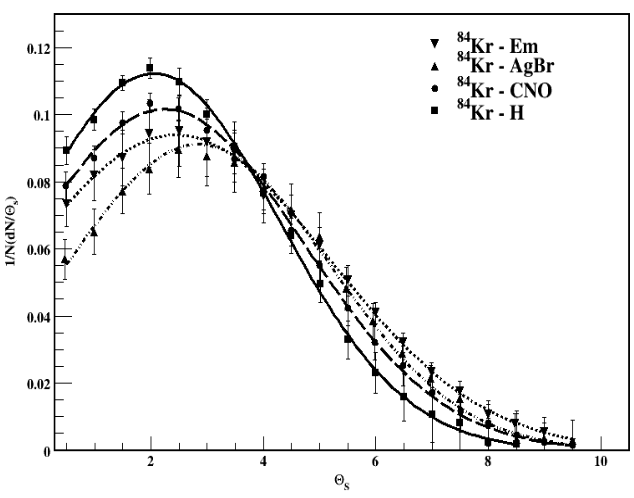


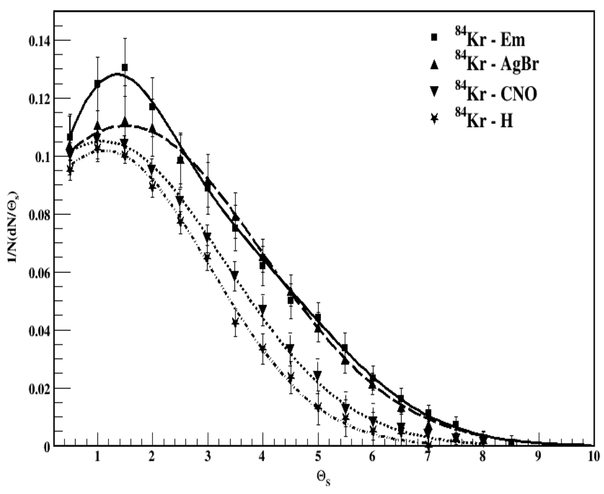
Derived temperature of hot and cold regions

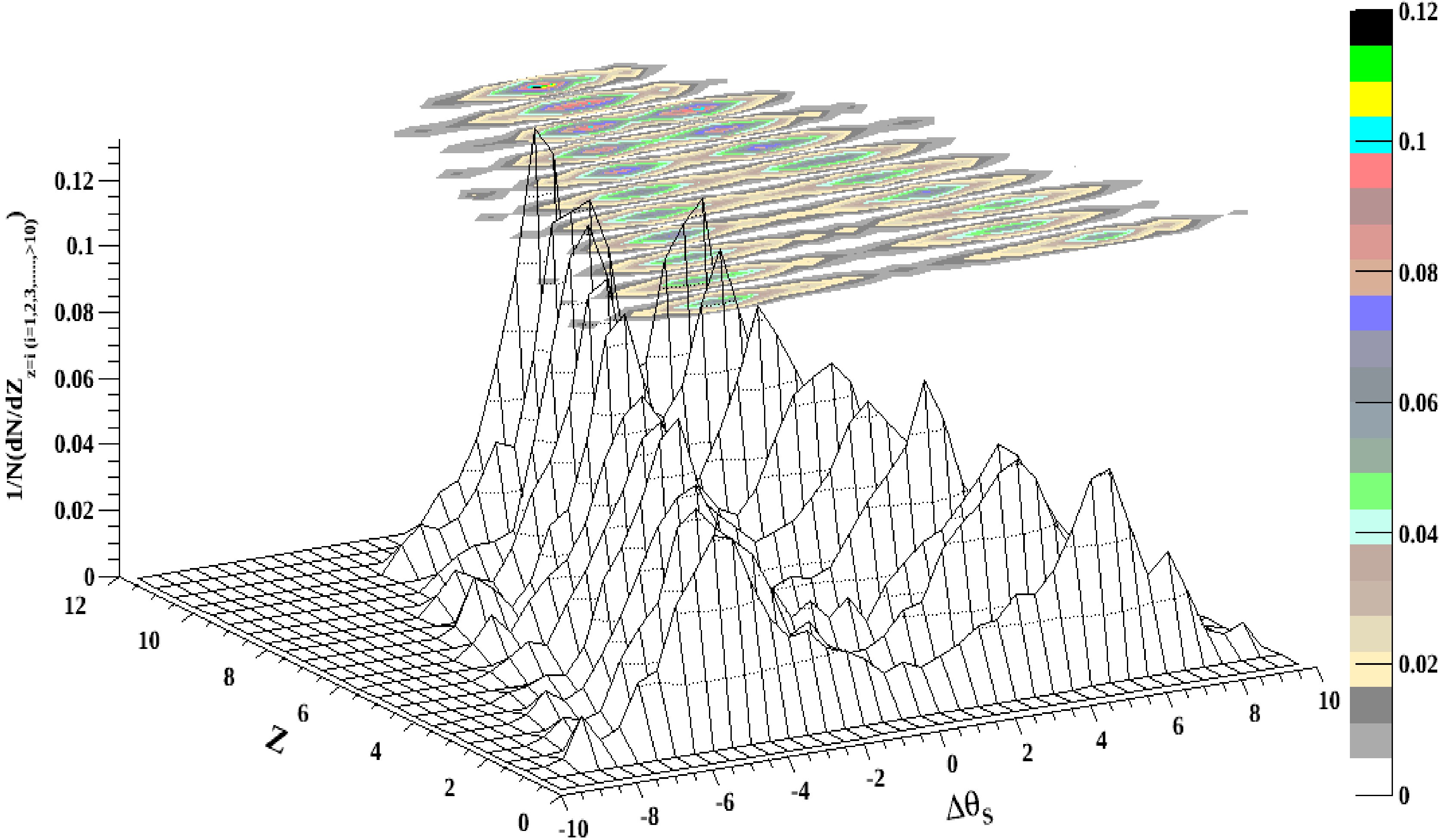
Emission Angle (space) Characteristics of Projectile Fragments





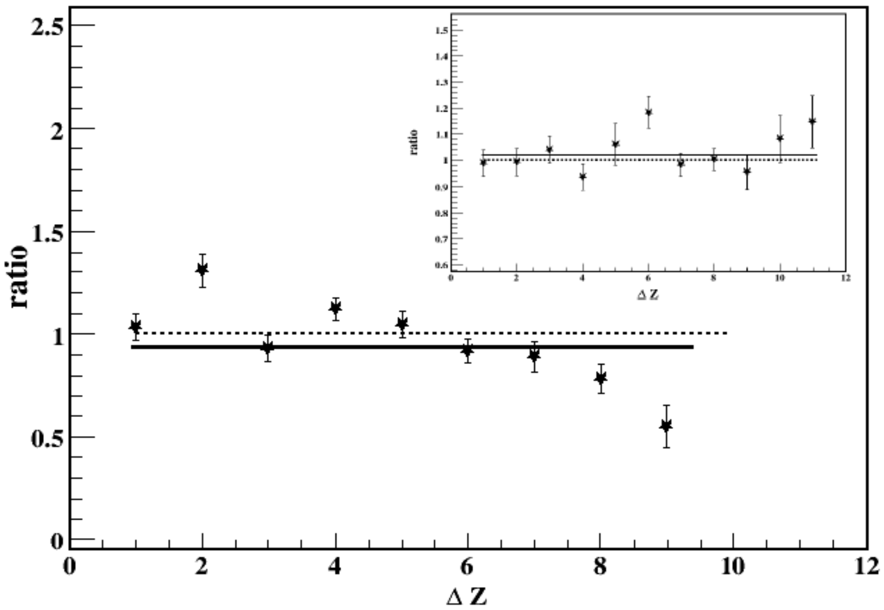




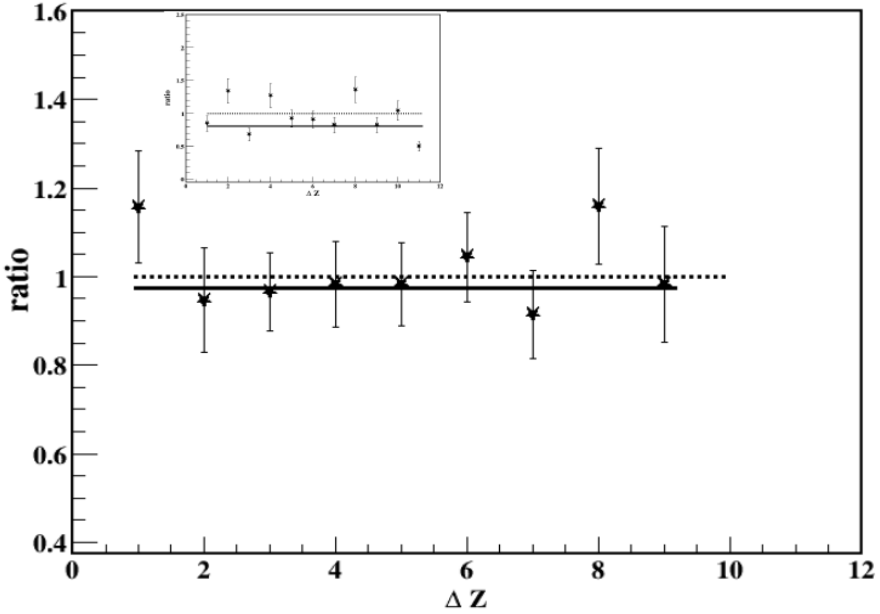


Normalized distribution of space angle difference between different projectile fragments.

Mean values



Area



Peak Area Ratio

Z	1	2	3	4	5	6	7	8	9	10	11
(a1+a2)/ {2*(A1+A2)} (%)	27.3	16.5	16.0	14.0	10.46	9.75	9.27	6.42	5.02	3.27	2.05

Conclusion

- The emission probability of single projectile fragment alpha in an interaction is gradually decreasing with projectile kinetic energy that reflects that the multiple projectile fragments alpha have more chance of emission during interaction keeping the average projectile fragments alpha value almost unchanged.

- The transverse momentum distributions of relativistic fragments can be described by two-source emission picture. The distribution of transverse momentum is the sum of two Rayleigh distributions

- we believe that the change in temperature in this part is sharp and follows an exponential law. Most of the emitted projectile fragments are from this region of the projectile spectator. As the projectile kinetic energy becomes less and less the area or volume of the rest part becomes larger and larger and play an important role of heavy fragment mission.

- Symmetric nature of projectile fragments w.r.to emission angle irrespective of charge.

- The secondary decay contributes toward the small peaks and it’s contribution decreases with the charge of PF’s .


Thank You!