Multiparticle He Fragmentation of $^{22}\text{Ne}$, $^{24}\text{Mg}$ and $^{28}\text{Si}$ in Emulsion at 4.1-4.5 A GeV/c.

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BECQUEREL Collaboration
I. Experimental details.

NIKFI BR-2 stacks of nuclear emulsions, 600µm thick, have been exposed horizontally to the α conjugate nuclei $^{22}\text{Ne}, ^{24}\text{Mg}$ and $^{28}\text{Si}$ at the DUBNA synchrophasotron.

Only the collisions with three and more He fragments in the final state – $N_{\text{He}} \geq 3$ have been used for the analysis.

Only the collisions with the sum charge in the narrow forward cone, been approximately equal to that of projectile one – $\Sigma Z_{\text{fr}} = Z_0 \pm 1$, have been analyzed.

Limitation $\Sigma Z_{\text{fr}} = Z_0 \pm 1$ means that extra peripheral collisions have been selected for analyses only.

Peripheral collisions usually have very limited number of target fragments and produced particles.
An example of $^{28}\text{Si}$ interaction with 6 He fragments.
The sum charge in the narrow forward cone (\(\Theta^\circ<2.55^\circ\)) is equal to \(\Sigma Z_{fr} = 2\times6+1 = 13\)

<table>
<thead>
<tr>
<th>N</th>
<th>Z</th>
<th>A</th>
<th>(\Theta^\circ)</th>
<th>(\Psi^\circ)</th>
<th>(\varphi^\circ)</th>
<th>(\alpha^\circ)</th>
<th>P,GeV/c</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>4</td>
<td>0.13</td>
<td>224.80</td>
<td>-0.09</td>
<td>-0.09</td>
<td>19.4±5.0</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>4</td>
<td>0.48</td>
<td>16.80</td>
<td>0.46</td>
<td>0.14</td>
<td>22.1±7.0</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>3</td>
<td>0.52</td>
<td>35.66</td>
<td>0.42</td>
<td>0.31</td>
<td>13.1±3.5</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>4</td>
<td>0.60</td>
<td>80.32</td>
<td>0.10</td>
<td>0.60</td>
<td>17.0±2.0</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>4</td>
<td>0.74</td>
<td>129.49</td>
<td>-0.47</td>
<td>0.57</td>
<td>19.1±3.1</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>3</td>
<td>1.77</td>
<td>75.86</td>
<td>0.43</td>
<td>1.72</td>
<td>12.1±2.9</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td></td>
<td>0.30</td>
<td>119.27</td>
<td>-0.15</td>
<td>0.26</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td></td>
<td>6.48</td>
<td>174.58</td>
<td>-6.45</td>
<td>0.61</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td></td>
<td>20.85</td>
<td>236.59</td>
<td>-11.85</td>
<td>-17.28</td>
<td></td>
</tr>
</tbody>
</table>
So it looks in the emulsion.
300 mkm from collision center.
II. The statistics of collisions used for analyses.

<table>
<thead>
<tr>
<th>( A_0 )</th>
<th>( P_0, \text{ GeV/c} )</th>
<th>( (N_{He}=3) )</th>
<th>( (N_{He}=4) )</th>
<th>( (N_{He}=5) )</th>
<th>( (N_{He}=6) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( ^{22}\text{Ne} )</td>
<td>4.1</td>
<td>238</td>
<td>79</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>( ^{24}\text{Mg} )</td>
<td>4.5</td>
<td>28</td>
<td>45</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>( ^{28}\text{Si} )</td>
<td>4.5</td>
<td>107</td>
<td>40</td>
<td>21</td>
<td>13</td>
</tr>
</tbody>
</table>

It isn’t minimum bias data set.
III. The multiplicities of He fragments
The multiplicity distributions of He fragments

- $^{22}$Ne
- $^{24}$Mg
- $^{28}$Si

$\Delta N/N$

$N_{He}$

- $0.11 \pm 0.01$
- $0.14 \pm 0.03$
- $0.14 \pm 0.02$
Integral multiplicity distribution of He fragments has a break at $N_{\text{He}}=2$.

It is minimum biased data set.
Dependence of average number of projectile fragments with $Z_{fr} = 2$ and $Z_{fr} \geq 3$ on the projectile charge $Z_0$. 

\[ \langle N_{fr} \rangle = 0.20 + 0.08 \cdot Z_0 \] 

9%
IV. The angles of He fragments
The projectile fragmentation cone is defined by a boundary angle $\theta_b$:

$$\sin \theta_b = \frac{0.2}{P_0}.$$
Angles of He fragments decreases with increasing of He fragment multiplicity in collision.

\[ \langle \theta^\circ \rangle_{\text{He}} \]

\[ N_{\text{He}} - \text{He fragment multiplicity} \]

\[ ^{22}\text{Ne} \]
\[ ^{24}\text{Mg} \]
\[ ^{28}\text{Si} \]
Integral angular spectrum of He fragments may be fitted by a line.
Integral $P_{\perp}^2$ distributions of He fragments may be fitted by a line with break at $P_{\perp}^2 \approx (0.5 - 0.6)$ GeV/c$^2$. 
V. Distributions of the excitation energy

- The reconstructed excitation energy spectrum for decays $^8\text{Be} \rightarrow 2\alpha$ and $^{12}\text{C} \rightarrow 3\alpha$ with respects to the ground state of the nuclei $^8\text{Be}$ and $^{12}\text{C}$ have been analyzed.

- The comparison with the exited levels of the nuclei $^8\text{Be}$ and $^{12}\text{C}$ have been done.
Excitation energy spectrum for decay $^{8}\text{Be} \rightarrow 2\alpha$.

Sum of channels with $\geq 3\alpha$ in final state.

$^{22}\text{Ne}$, $^{24}\text{Mg}$, $^{28}\text{Si}$
Excitation energy spectrum for decay $^8\text{Be} \rightarrow 2\alpha$.

Channels with $5\alpha$ in final state.

Ex($^8\text{Be}$), MeV  
Ex($^8\text{Be}$), MeV  
dN/N  

$^22\text{Ne}$  
$^{24}\text{Mg}$  
$^{28}\text{Si}$
Excitation energy spectrum for decay $^{8}\text{Be} \rightarrow 2\alpha$.

Interaction of $^{22}\text{Ne}$ at 4.1 $\text{A GeV/c}$. 

$N_{\text{He}}=3$

$N_{\text{He}}=4$

$N_{\text{He}}=5$
Excitation energy spectrum for decay $^{12}\text{C} \rightarrow 3\alpha$. 
Sum of channels with $\geq 3\alpha$ in final state.

- $dN/N$ vs $E_x(^{12}\text{C})$, MeV
  - $^{24}\text{Mg}$
  - $^{22}\text{Ne}$
  - $^{28}\text{Si}$

- $N(\geq E_x),%$ vs $E_x(^{12}\text{C})$, MeV
  - $^{22}\text{Ne}$
  - $^{24}\text{Mg}$
  - $^{28}\text{Si}$
Excitation energy spectrum for decay $^{12}\text{C} \rightarrow 3\alpha$.
Cannels with $4\alpha$ in final state.
Excitation energy spectrum for decay $^{12}\text{C} \rightarrow 3\alpha$.

Interaction of $^{28}\text{Si}$ at 4.5 A GeV/c.
**VI. Conclusions.**

**Multiplicity.**

- Characteristics of projectile _He fragments_ from collision of $^{22}\text{Ne}$, $^{24}\text{Mg}$ and $^{28}\text{Si}$ in emulsion at 4.1-4.5 A GeV/c have been studies. Only the collisions with $\geq 3$ He fragments and with the sum charge in the forward narrow cone, been equal to that of projectile one, have been analyzed.

- Integral multiplicity distribution of He fragments may be fitted by a line with a break at $N_{He}=2$.

- In the region under investigation average number of He fragments increases with increasing of projectile charge as $0.20+0.08\cdot Z_0$; at the same time average number of fragments with $Z_{fr} \geq 3$ is approximately constant.

- It means, that increasing of projectile fragments number with increasing of projectile charge is due to number of fragments with charges 1 and 2.
VI. Conclusions.

Angles.

- Angles of He fragments decrease with increasing of He fragment multiplicity in collision.
- Integral angular spectrum of He fragments may be fitted by a line.
- There is no difference in angles of He fragments from $^{22}\text{Ne}$, $^{24}\text{Mg}$ and $^{28}\text{Si}$ interaction.
VI. Conclusions.

Excitation energy.

- The first four excited levels ($E_x < 15$ MeV) are mostly responsible for $^8\text{Be} \rightarrow 2\alpha$ decays in our experiment.

- There is no differences in the excitation energy spectrum for decays $^8\text{Be} \rightarrow 2\alpha$ for $^{22}\text{Ne}$, $^{24}\text{Mg}$ and $^{28}\text{Si}$ collisions from one side and for channels with 3, 4, 5 and 6 He fragments in final states from other.

- The exited levels in the interval $E_x < 15-20$ MeV are mostly responsible for $^{12}\text{C} \rightarrow 3\alpha$ decays in our experiment. The first available level $O^+ - 7.65$ MeV is represented weakly.

- There is no significant difference in the excitation energy spectrum for decays $^{12}\text{C} \rightarrow 3\alpha$ for $^{22}\text{Ne}$, $^{24}\text{Mg}$ and $^{28}\text{Si}$ collisions from one side and for channels with 3, 4, 5 and 6 He fragments in final states from other.