Clustering features of ^{14}N in relativistic multifragmentation process

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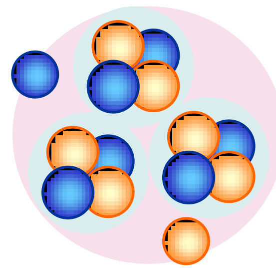
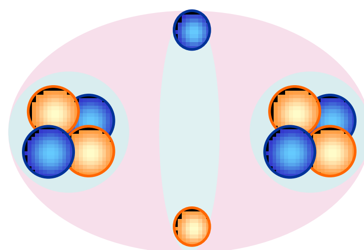
Statement of experimental research

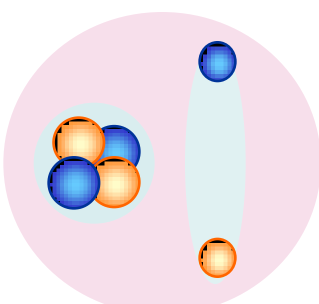
Alpha - deuteron clusterisation for ^{6}Li, ^{10}B, ^{14}N nuclei



$$^{14}N \rightarrow \frac{3He + p}{3He + d} \quad ?$$



$$^{10}B \rightarrow \frac{2He + p}{2He + d} \cong 1$$



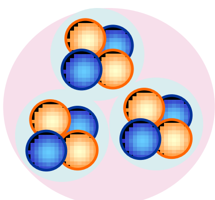
$$^{6}Li \rightarrow \frac{He + p}{He + d} \cong 1$$

$^{6}Li \rightarrow$ Phys. Atom. Nucl. 62, №8, p. 1378-1387, (1999).

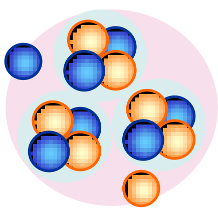
$^{10}B \rightarrow$ Phys. Atom. Nucl. 66, №9, p. 1646-1650, (2004).

Statement of experimental research

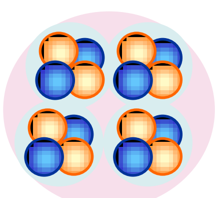
Alpha – clusterisation in the relativistic dissociation ^{12}C, ^{14}N и ^{16}O nuclei



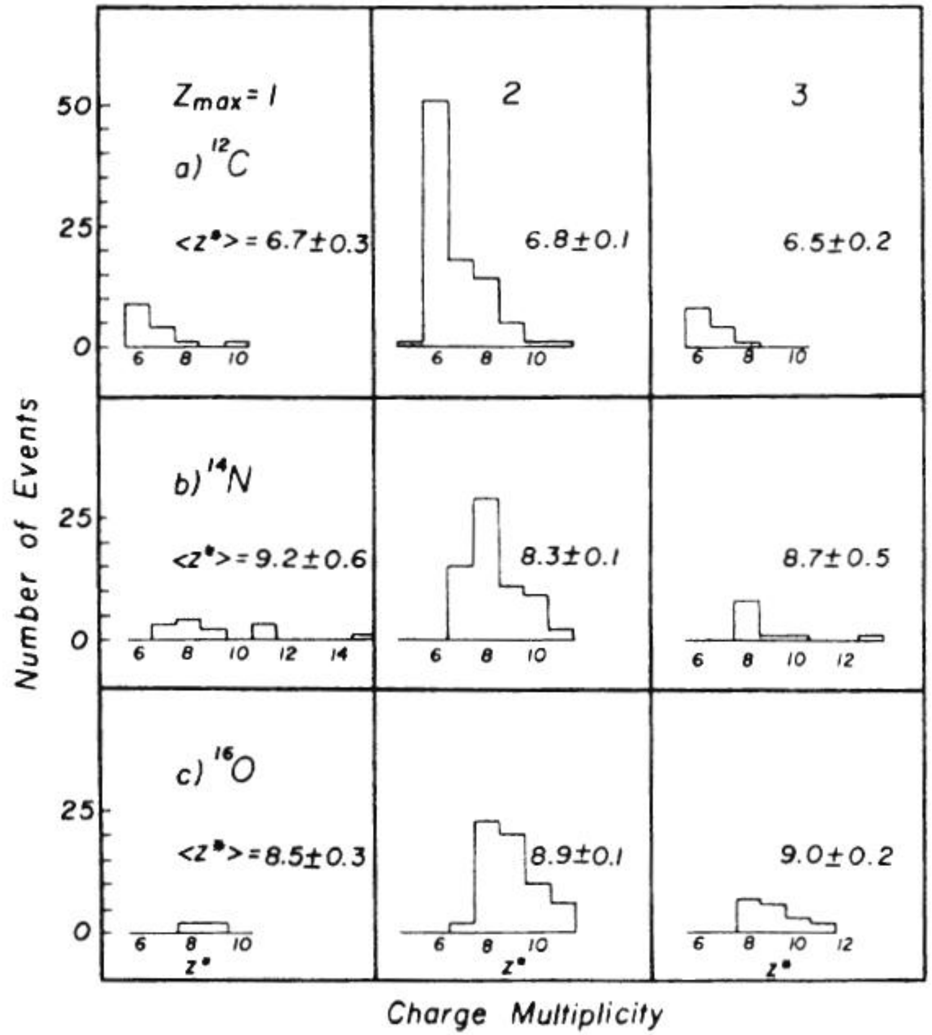
$$^{12}C \rightarrow 3\alpha$$



$$^{14}N \rightarrow 3\alpha + X$$

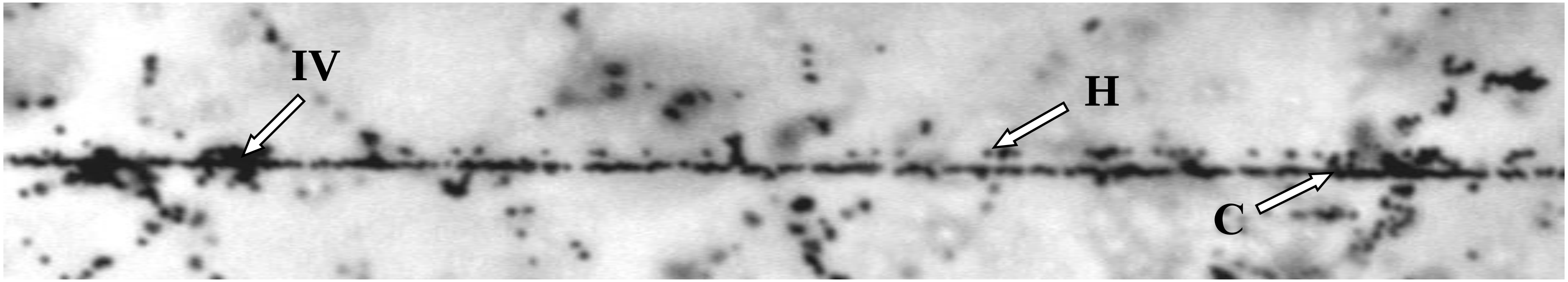


$$^{16}O \rightarrow 4\alpha$$

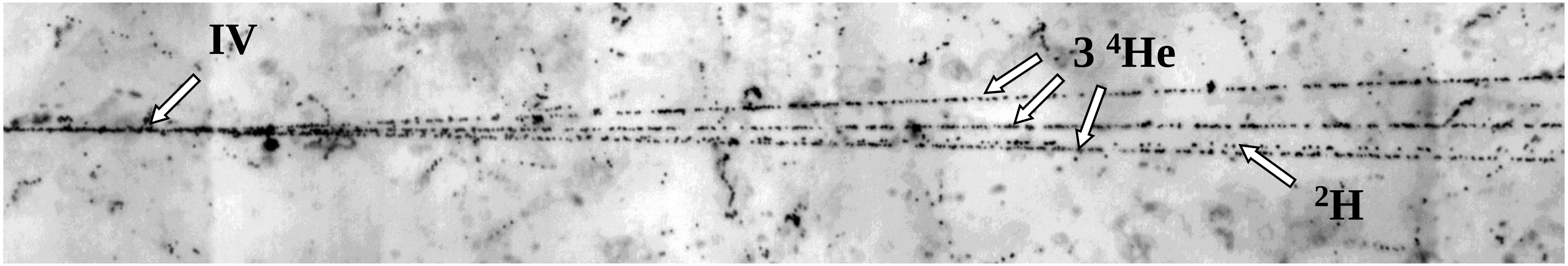


H.Heckman, D.E.Greiner, P.J.Lindstrom, and Shwe *Fragmentation of ^4He, ^{12}C, ^{14}N and ^{16}O nuclei in nuclear emulsion at 2.1 GeV/nucleon* Phys.Rev. C 17, №5 1735 (1978).

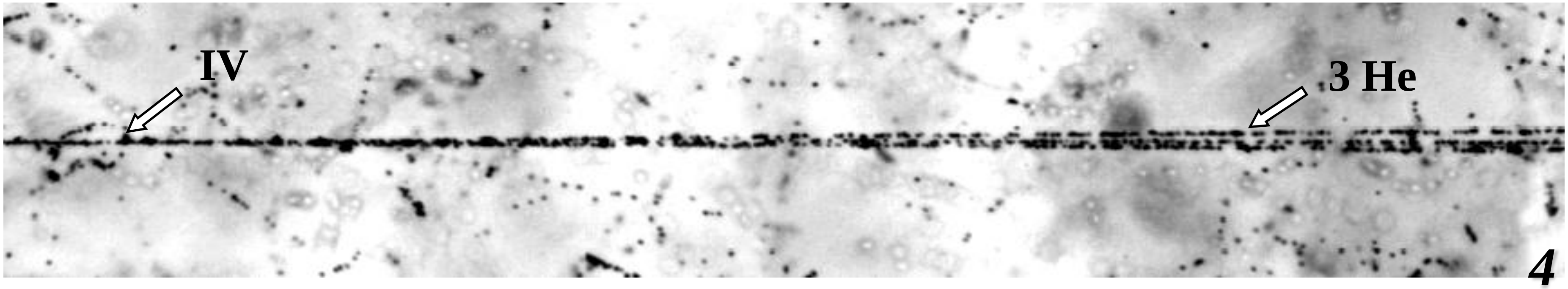
Two-particle fragmentation channels $^{14}N \rightarrow C + H$, $^{14}N \rightarrow B + He$



Total fragments identification for dissociation mode $^{14}N \rightarrow 3He + H$



Inelastic charge-exchange processes $^{14}N \rightarrow 3He$, $^{14}N \rightarrow 2He + 2H$, $^{14}N \rightarrow 3He + 2H$



Aim of investigation was devoted to the progress in experimental results in a detailed study of nucleon clustering in the ^{14}N nucleus dissociation with the highest complete usage of emulsion technique

- ✓ **charge measurements**,
- ✓ **angles, projected onto emulsion plane as well as dip-angles measurements**,
- ✓ using the multiple Coulomb scattering method for **identification of single- and double-charged fragments**.

Emulsion irradiation, scanning along the track, determination of free path with respects to inelastic interactions

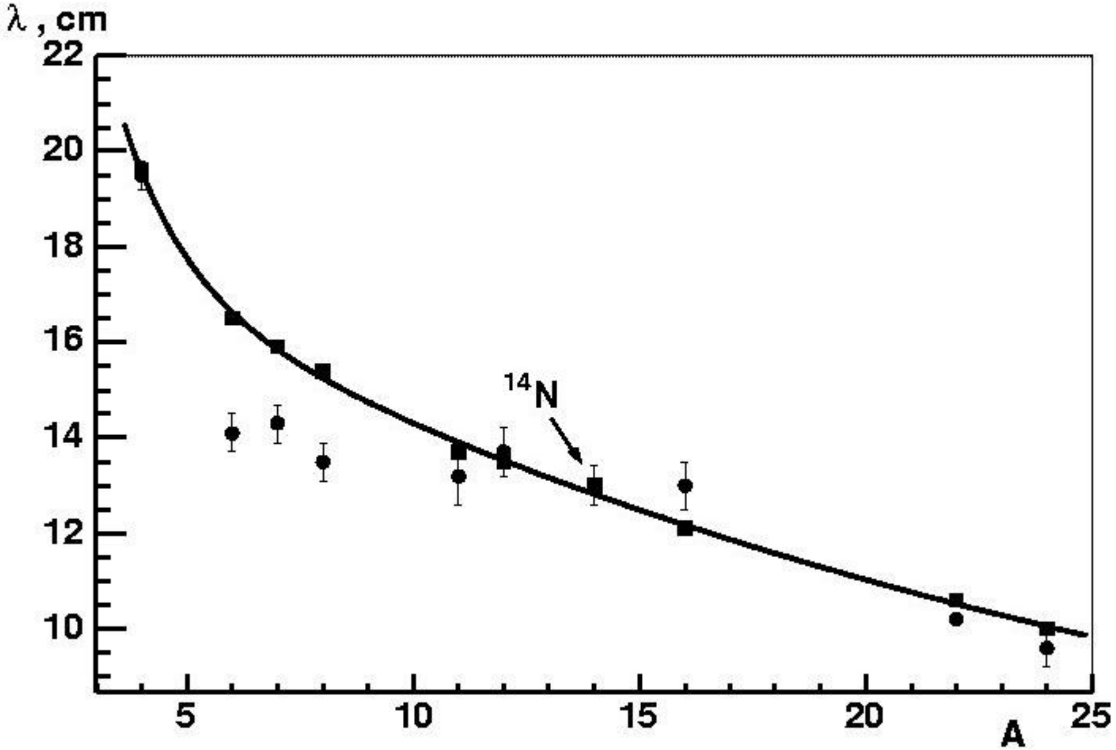
P_0 = 2.86 A GeV/c,

Sum of the track length ***123.71 m***

N_Σ = 951 inelastic interaction

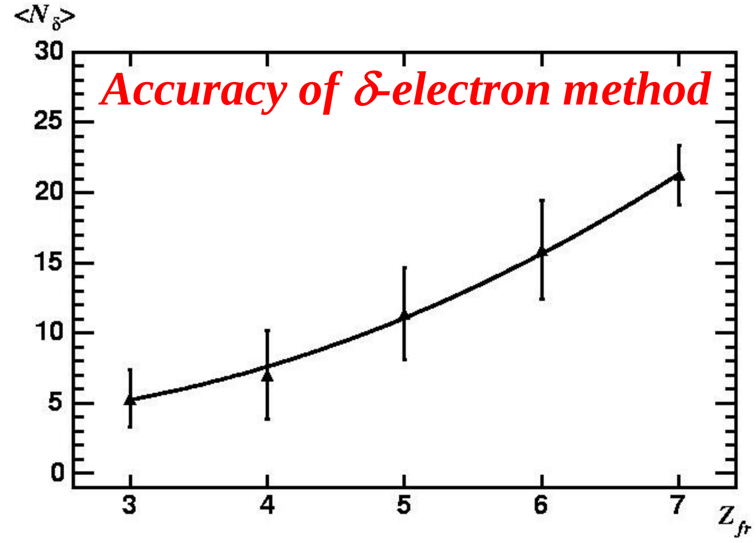
λ = 13.0 ± 0.4 cm

Emulsion irradiation in a beam of ^{14}N nuclei was accelerated on the JINR Nuclotron, 2003.



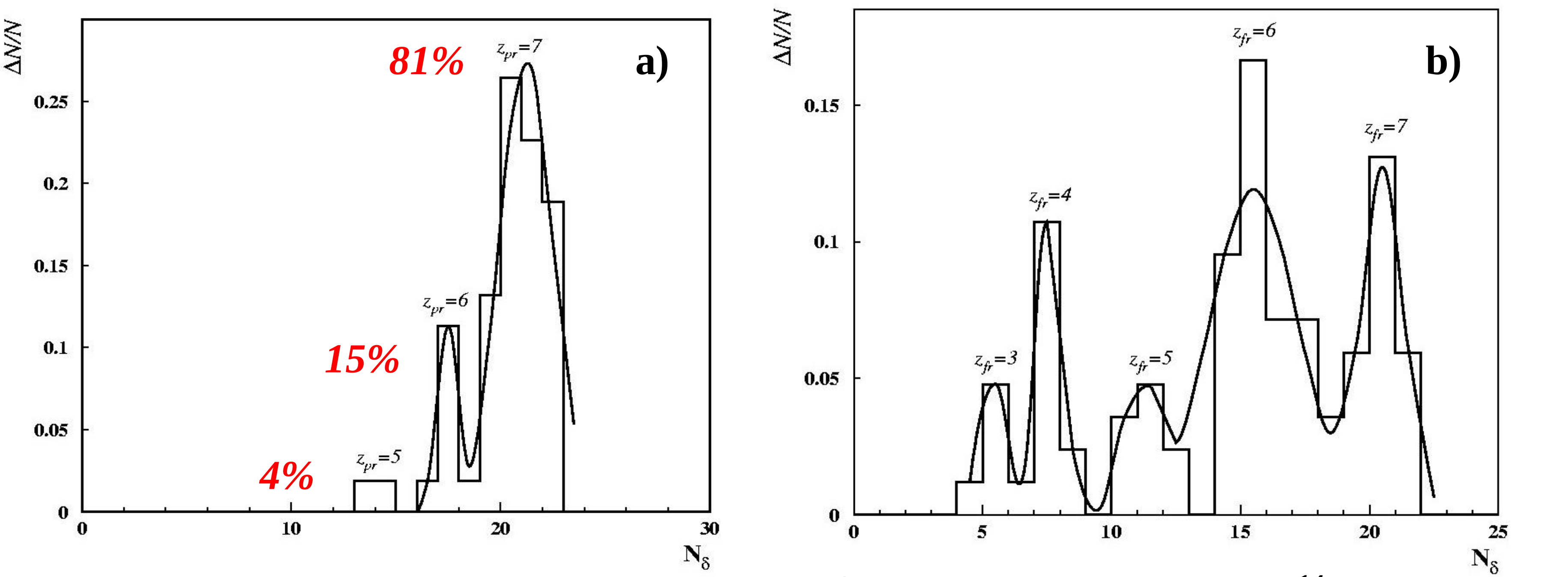
Mean range of free path with respects to inelastic interactions in the photoemulsion as a function of the projectile mass number *(A)*. The curve represents the fit, obtained within the geometric model.

Charge definition for beam nucleus tracks and fragments



$$N_\delta = a\,Z^{\,2} + b$$

$$a = 0.55,\;\; b = 4.82 \;\; u \;\; \chi^2 = 0.05$$



Distribution by the *δ*-electron number per *1* mm of the track on: a) primary ^{14}N nuclei, b) ^{14}N nucleus fragments with *3 - 7* charges.
The continuous line is the description by the Gauss function sum.

The charge topology distribution of the “white” stars and the interactions involving the target-nucleus fragment production in the ^{14}N dissociation

Z_{fr}	6	5	5	4	3	3	-	-	-
N_{z1}	1	-	2	1	4	2	3	1	5
N_{z2}	-	1	-	1	-	1	2	3	1
N_{ws}									
N_{tf}									
N_{in}									

Peripheral interactions distribution of ^{14}N nuclei with a momentum 2.86 A GeV/c (N_{in}) by the charge modes with $\Sigma_{Zfr}=7$ (161 events), including 61 «white» stars (N_{ws}), and 100 events with target fragments (N_{tf}) without charged mesons ($n_s=0$). N_{Z1}, N_{Z2}, – number of single- and two-charged fragments respectively. Every fragmentation channel are pointed in absolute values and in percent.

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N_{z1}	1	-	2	1	4	2	3	1	5
N_{z2}	-	1	-	1	-	1	2	3	1
N_{ws}	16	5	5	2	1	-	6	21	5
N_{tf}	24	4	3	5	2	3	21	35	3
N_{in}	40	9	8	7	3	3	27	56	8

Peripheral interactions distribution of ^{14}N nuclei with a momentum 2.86 A GeV/c (N_{in}) by the charge modes with Σ_{Zfr}=7 (161 events), including 61 «white» stars (N_{ws}), and 100 events with target fragments (N_{tf}) without charged mesons (n_s=0). N_{Z1}, N_{Z2}, – number of single- and two-charged fragments respectively. Every fragmentation channel are pointed in absolute values and in percent.

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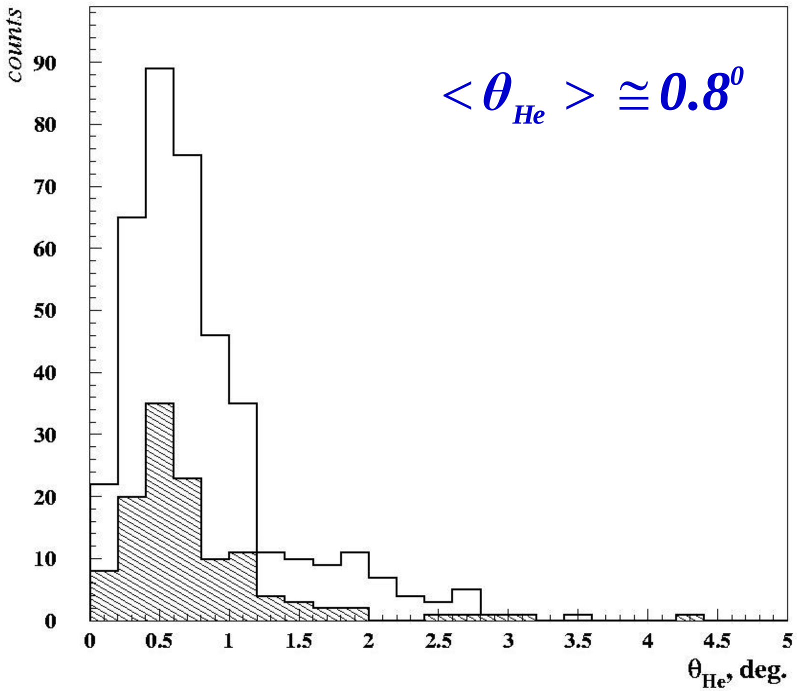
N_{z1}	1	-	2	1	4	2	3	1	5
N_{z2}	-	1	-	1	-	1	2	3	1
N_{ws}	16 26%	5 8%	5 8%	2 3%	1 2%	- -	6 10%	21 35%	5 8%
N_{tf}	24 24%	4 4%	3 3%	5 5%	2 2%	3 3%	21 21%	35 35%	3 3%
N_{in}	40 25%	9 5%	8 5%	7 4%	3 2%	3 2%	27 17%	56 35%	8 5%

Peripheral interactions distribution of ^{14}N nuclei with a momentum 2.86 A GeV/c (N_{in}) by the charge modes with ΣZ_{fr}=7 (161 events), including 61 «white» stars (N_{ws}), and 100 events with target fragments (N_{tf}) without charged mesons (n_s=0). N_{Z1}, N_{Z2}, – number of single- and two-charged fragments respectively. Every fragmentation channel are pointed in absolute values and in percent.

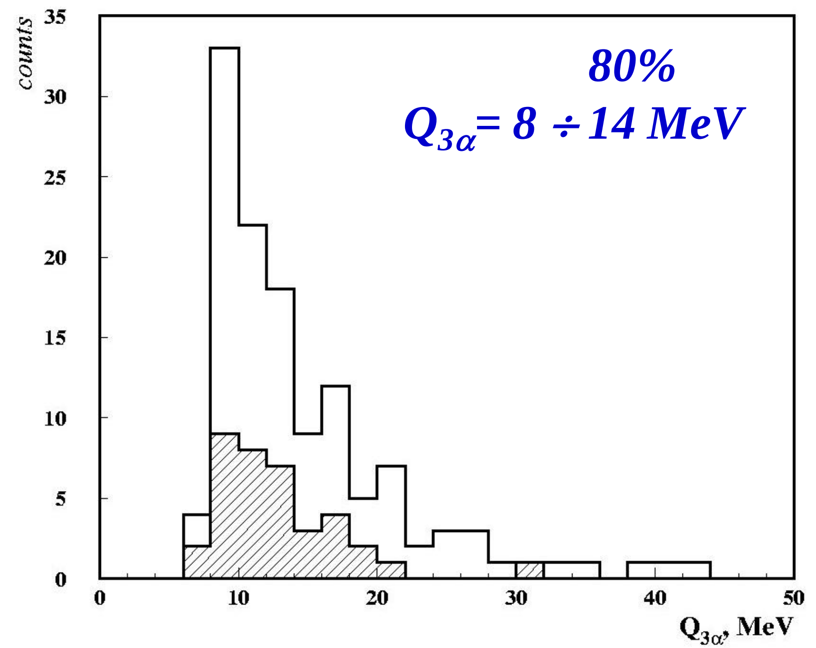
An accelerated viewing for the major dissociation channel $^{14}N \to 3\alpha + X$



$$N_{in}(^{14}N \to 3\alpha + X) = 132$$

$$N_{ws}(^{14}N \to 3\alpha + X) = 41$$

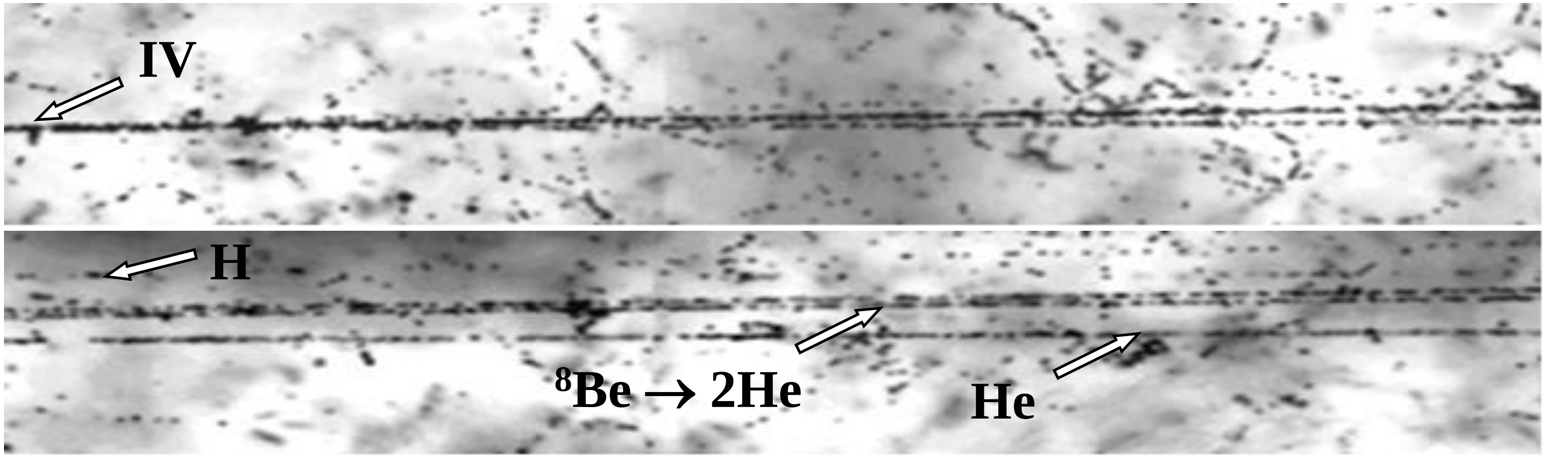
$$\sin\theta_{fr}(^{14}N) = \frac{0.2\ \ GeV/c}{2.86\ \ GeV/c} = 0.07 \Rightarrow \theta_{fr} \cong 4^0$$



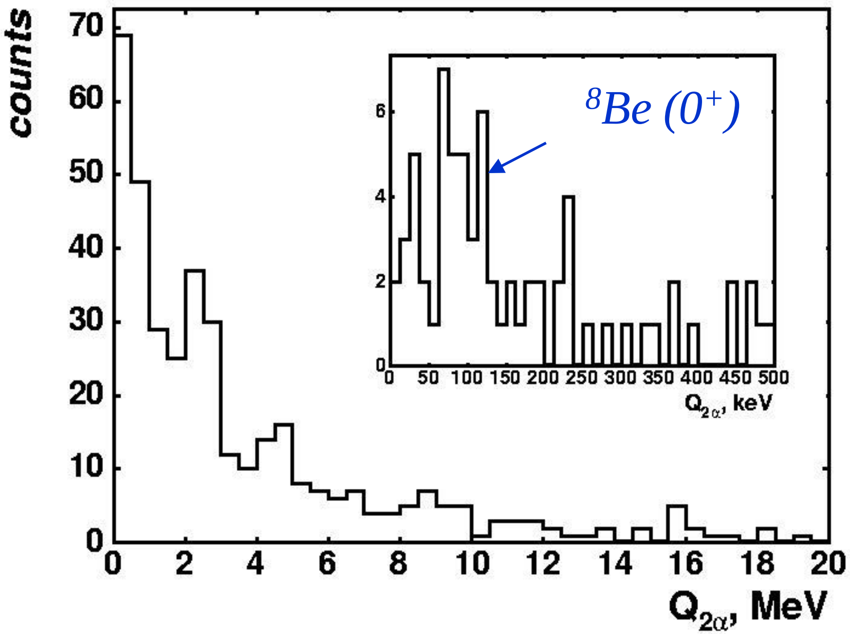
$$Q_{3\alpha} = M^*_{3\alpha} - m_C$$

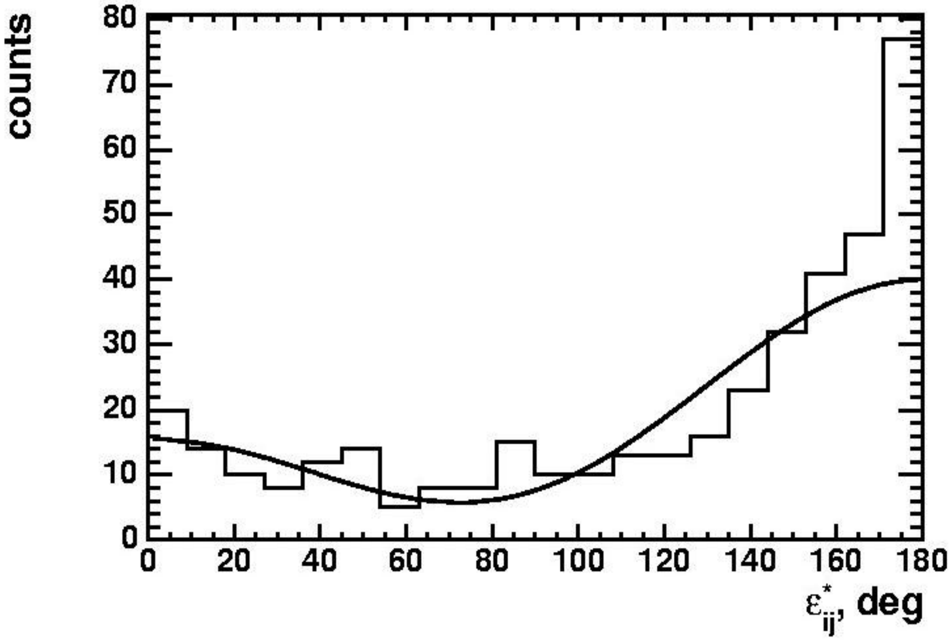
$$M^*_{3a} = \sum_{i,j=1}^{3} (\boldsymbol{P}_i \boldsymbol{P}_j)$$

^{8}Be formation in $^{14}N \to 3\alpha + X$ fragmentation channel



25% $^{14}N \to {}^{8}Be + He + X$





Single- and double-charged fragments identification from $^{14}N_{ws} \rightarrow 3He + H$ using the multiple Coulomb scattering method

$^{3}He : {}^{4}He : {}^{6}He = 3 : 8 : 1$

$$^{6}Li \rightarrow \frac{He + p}{He + d} \cong 1$$

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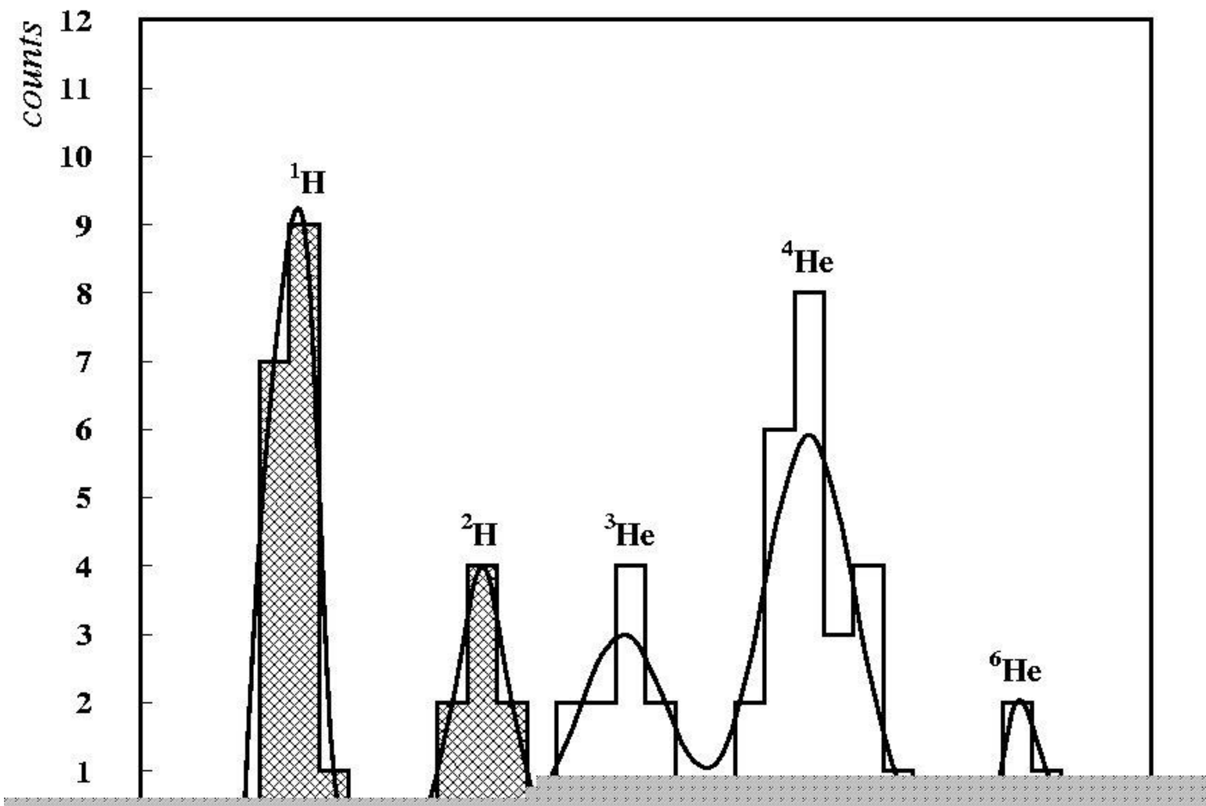
$$^{14}N \rightarrow \frac{3He + p}{3He + d} \cong 2$$



$^{6}Li \rightarrow$ Phys. Atom. Nucl. 62, №8, p. 1378-1387, (1999).

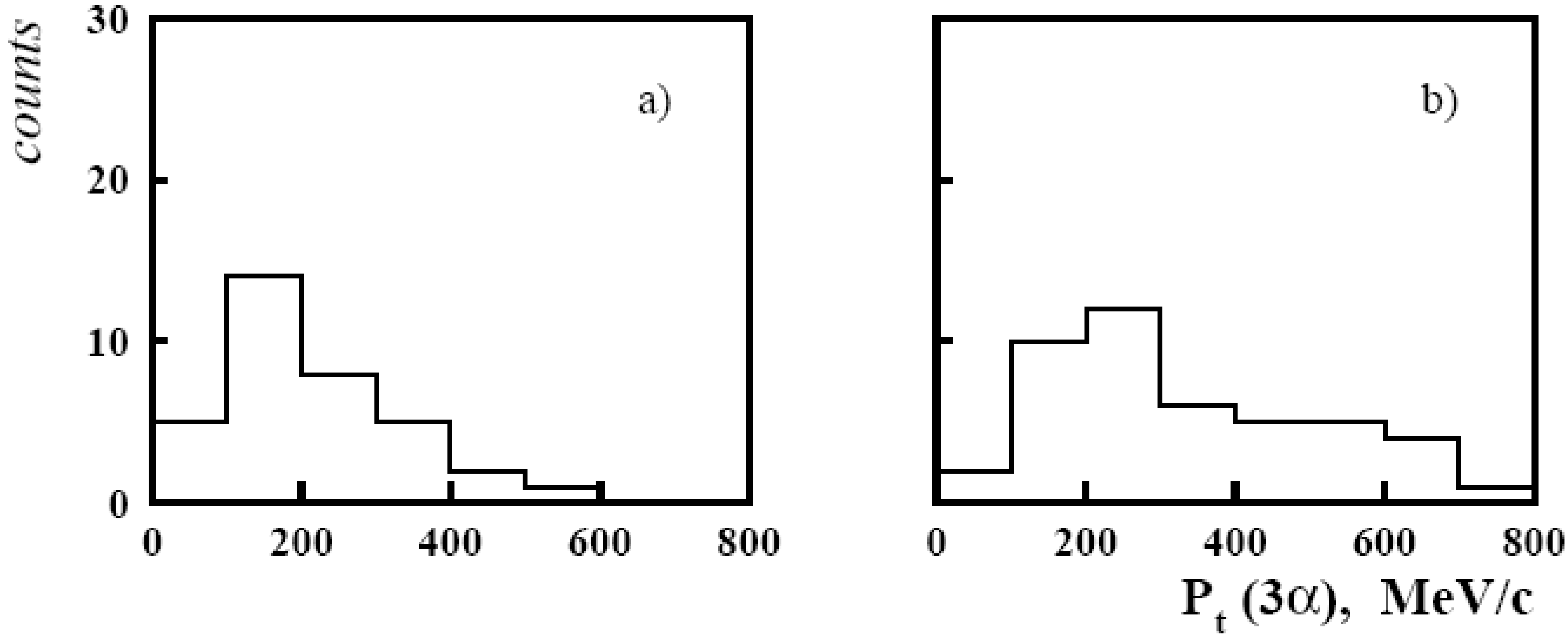
$^{10}B \rightarrow$ Phys. Atom. Nucl. 66, №9, p. 1646-1650, (2004).

$^{14}N \rightarrow$ Phys. Atom. Nucl. 70, №7, p. 1230-1234, (2007).

The mean transverse momentum transferred to the 3α-system

$<p_t(3\alpha)>_{ws} = 216 \pm 21$ MeV/c

$<p_t(3\alpha)>_{tf} = 334 \pm 27$ MeV/c



Transverse momentum distribution transferred to the 3α-system $P_t(3\alpha)$ for a) – "white" stars $^{14}N \rightarrow 3He + H$, $<P_t(3\alpha)> = 216 \pm 21$ MeV/c;
b) – interactions involving the production of one or a few target-nucleus fragments $^{14}N \rightarrow 3He + H + X$, $<P_t(3\alpha)> = 334 \pm 27$ MeV/c.

Two-particle fragmentation channels

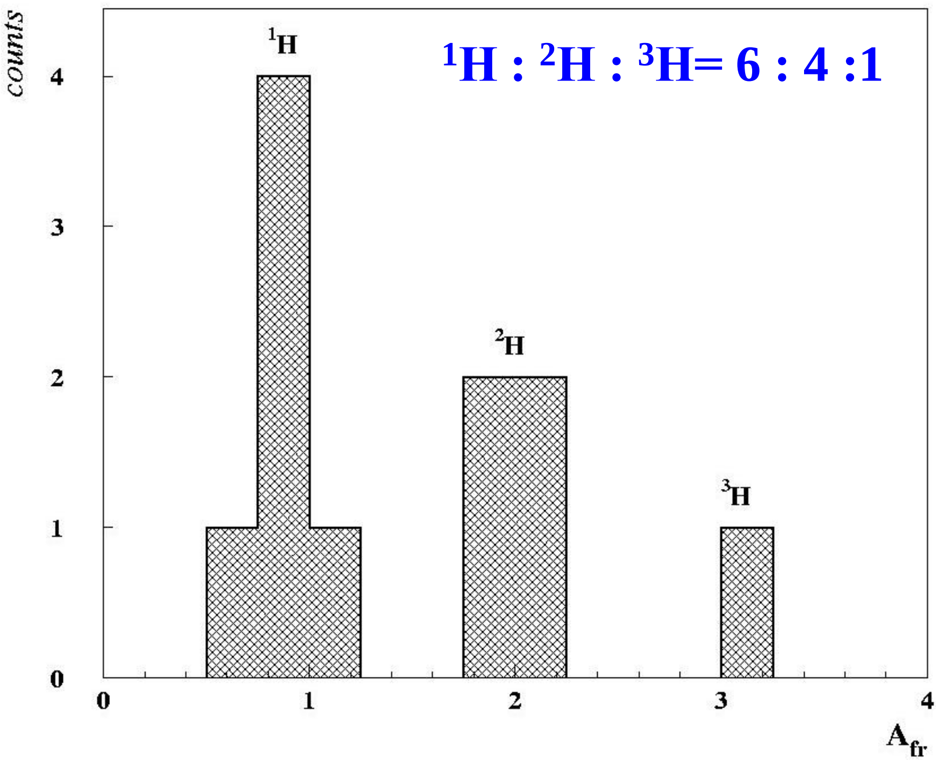
$^{14}N_{ws} \rightarrow C + H$ (11 events)

$W(^{14}N \rightarrow {}^{13}C + {}^{1}H) \approx 55\%, \quad Q_{C\,p} = 8\ MeV$

$W(^{14}N \rightarrow {}^{12}C + {}^{2}H) \approx 35\%, \quad Q_{C\,p} = 11\ MeV$

$W(^{14}N \rightarrow {}^{11}C + {}^{3}H) \approx 10\%, \quad Q_{C\,p} = 23\ MeV$

$\langle p_t(C + H)\rangle_{ws} = 160 \pm 20\ MeV/c$



$^{14}N_{ws} \rightarrow {}^{10}B + {}^{4}He$ (5 events)

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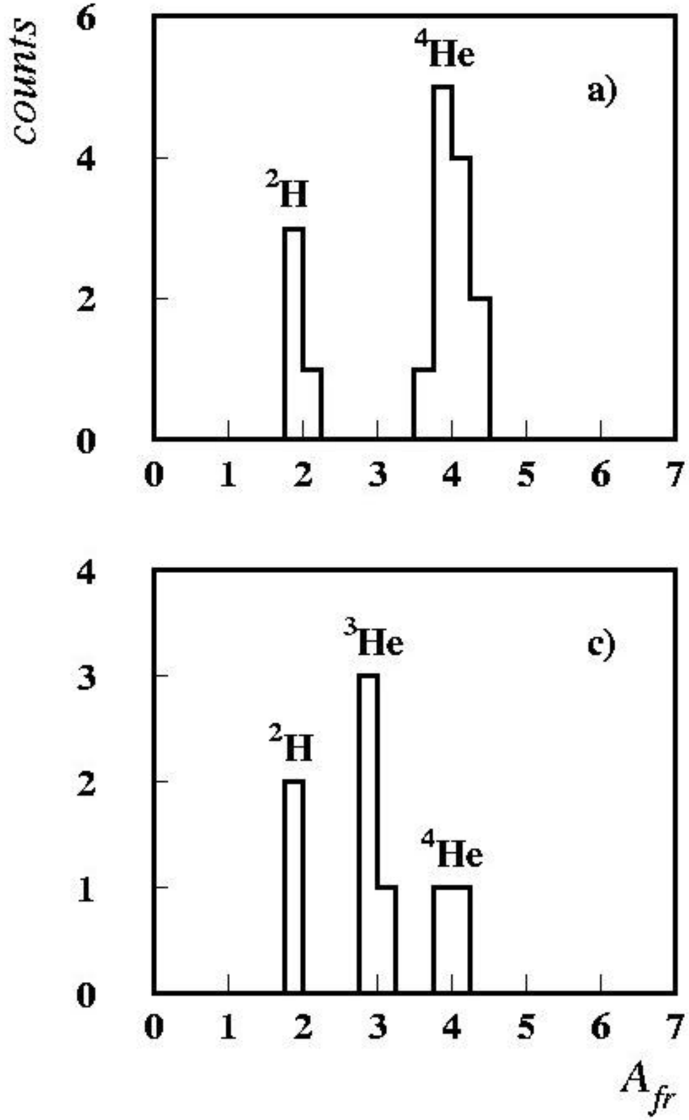
According to the available statistics only *ONE EVENT* $^{14}N_{ws} \rightarrow Li + Be$ was recorded

Completely identified modes $^{14}N_{ws} \to 3He + H$



a) - 4 events $^{14}N \to 3\ ^4He + d$, $Q = 18\ MeV$

b) - 3 events $^{14}N \to {}^6He + {}^4He + {}^3He + p$, $Q = 39\ MeV$

c) - 2 events $^{14}N \to {}^4He + 2\ ^3He + d$, $Q = 59\ MeV$

$< p_t(^6He + {}^4He + {}^3He + p) > = 431 \pm 43\ MeV/c$

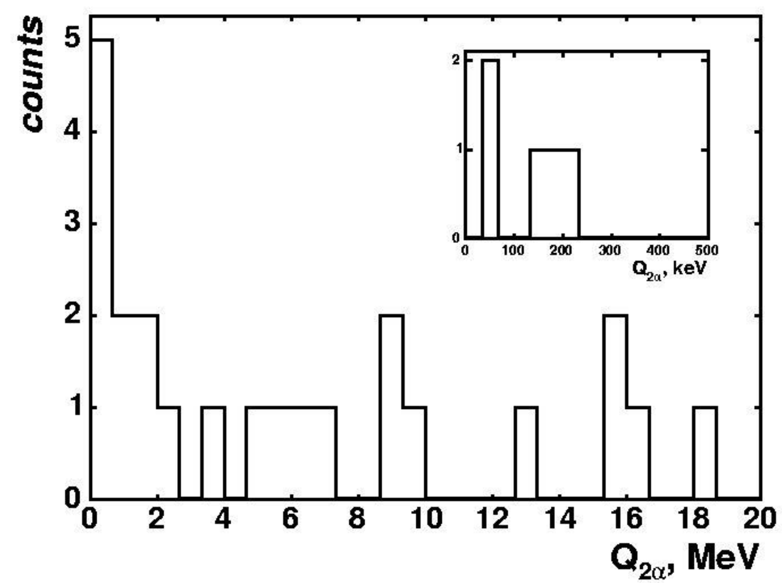
$< p_t(3\ ^4He + d) > = 182 \pm 90\ MeV/c$

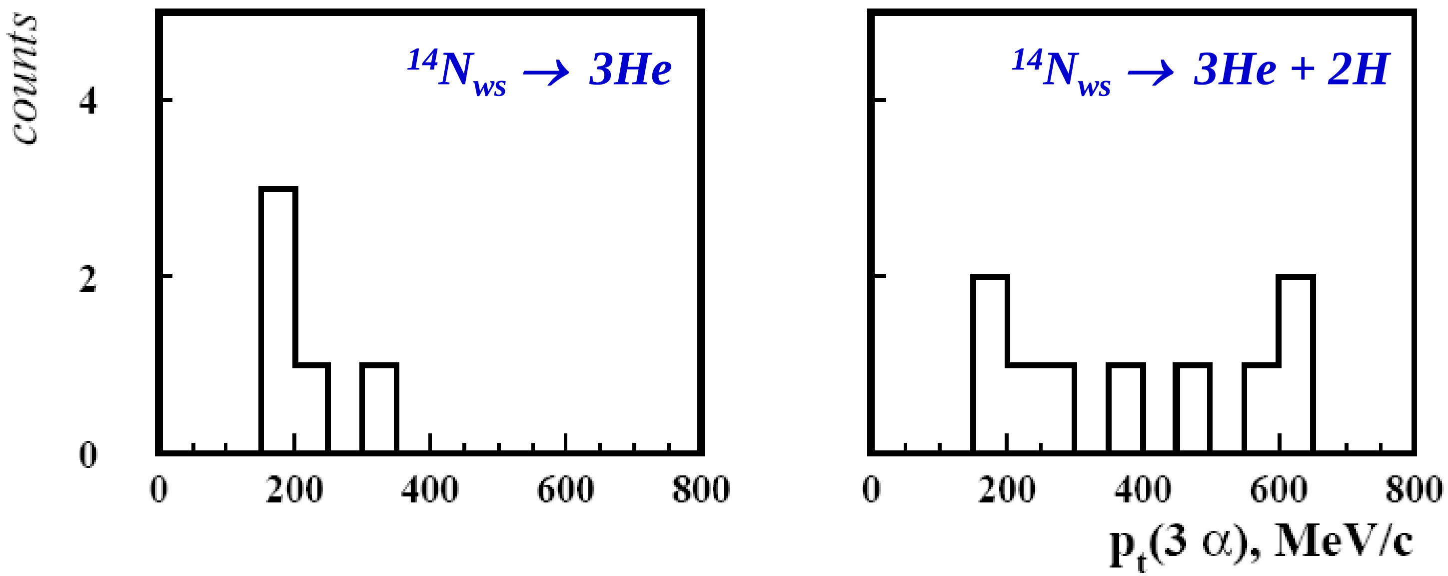
Experimental observation of inelastic charge-exchange processes

	$\Sigma Z_{fr} = 6$	$\Sigma Z_{fr} = 6$	$\Sigma Z_{fr} = 8$
N_{z1}	2	-	2
N_{z2}	2	3	3
N_{ws}	3	5	9
N_{tf}	2	7	1
N_{in}	5	12	10

3% (N_{ws}, N_{tf}, N_{in})

20% $\ ^{14}N_{ws} \rightarrow \ ^{8}Be + He + 2H$





For the first time the detailed picture of the ^{14}N nuclei dissociation in photo-emulsion, accelerated at the JINR Nuclotron, is studied. The basic conclusions of the research consist in the following:

1. **According to the available statistics, the fragmentation channel $^{14}N \rightarrow 3He + H$ plays a leading role in the charge topology distribution. It gives the contribution approximately *50%* both, for "white" stars, and for events with formation of target fragments and mesons. Thus, ^{14}N-nucleus is rather effective source for studying properties 3α-particle systems.**

2. **A total of *132* events in this channel which made it possible to estimate the energy scale of 3α-particle systems produced in peripheral fragmentation. An invariant estimation of the energy scale of 3α-system production performed under sufficiently reliable assumptions shows that *80%* of interactions are concentrated in the region below *14 MeV* which corresponds to ^{12}C cluster excitations. The contribution of the events $^{14}N \rightarrow {}^{8}Be + \alpha + X \rightarrow 3\alpha + X$ accompanied by an ^{8}Be decay from the ground state amounts to about *25%*. Production of ^{8}Be nucleus is clearly pronounced in a strongly asymmetric ε^{*}_{ij} distribution of α-particles pairs in the rest system of the 3α-particles.**

3. **The identification of relativistic H nuclei in the channel $^{14}N \rightarrow 3He + H$ points to a noticeable decrease of the deuteron yield with respect to the protons compared with early studied cases of relativistic fragmentation $^{6}Li \rightarrow He + H$ and $^{10}B \rightarrow 2He + H$.**

4. **The total transverse momentum distributions Σp_t of α-fragments in the $^{14}N \rightarrow 3He + X$ are studied. The mean value of Σp_t for the "white" stars is appreciably smaller then for events accompanied by the production of target fragments.**

5. **For the first time processes relativistic dissociation of ^{14}N nuclei: $^{11}C + {}^{3}H$, $^{6}He + {}^{4}He + {}^{3}He + p$, $^{4}He + 2{}^{3}He + d$ have been completely identified for which nucleon regrouping beyond the alpha bounds and so overcoming of high energy thresholds Q are needed.**

- **N.P. Andreeva, … T.V.Shchedrina et al., *«Clustering in light nuclei in fragmentation above 1 A GeV»*, Eur.Phys.J. A 27S1 (2006) 295-300.**

- **T.V.Shchedrina... et al., *« Peripheral interactions of relativistic ^{14}N nuclei with emulsion nuclei»*, Phys. Atom. Nucl. 70, №7 (2007) 1230-1234.**