Fragmentation of relativistic nuclei in peripheral interactions in nuclear track emulsion

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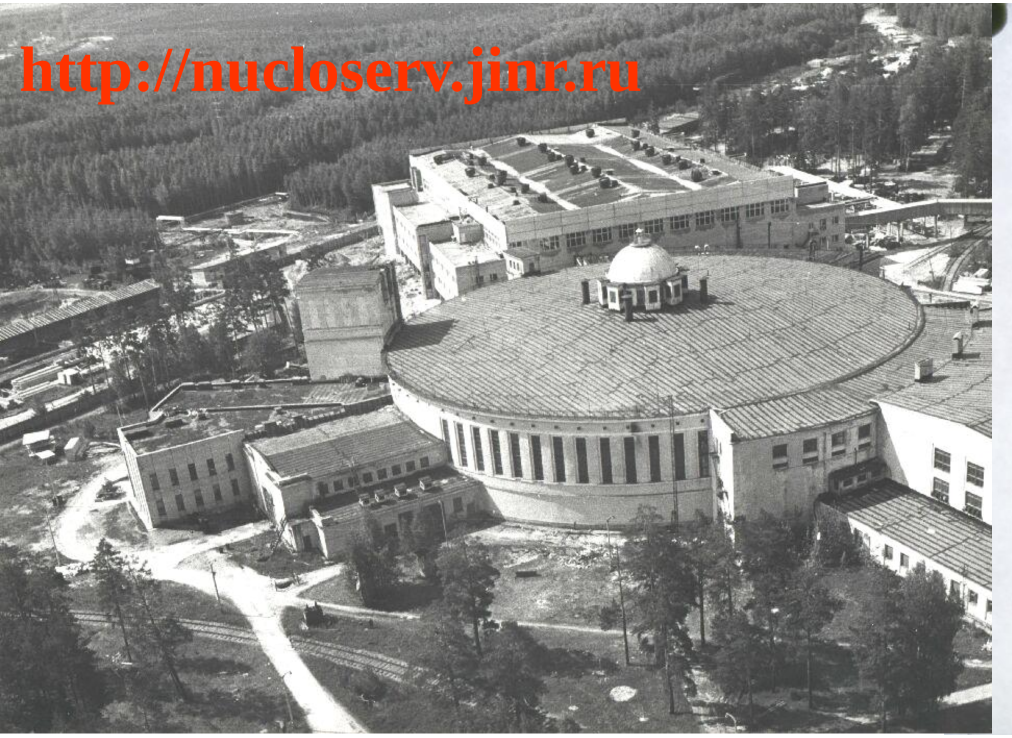
JINR (for the BECQUEREL collaboration)

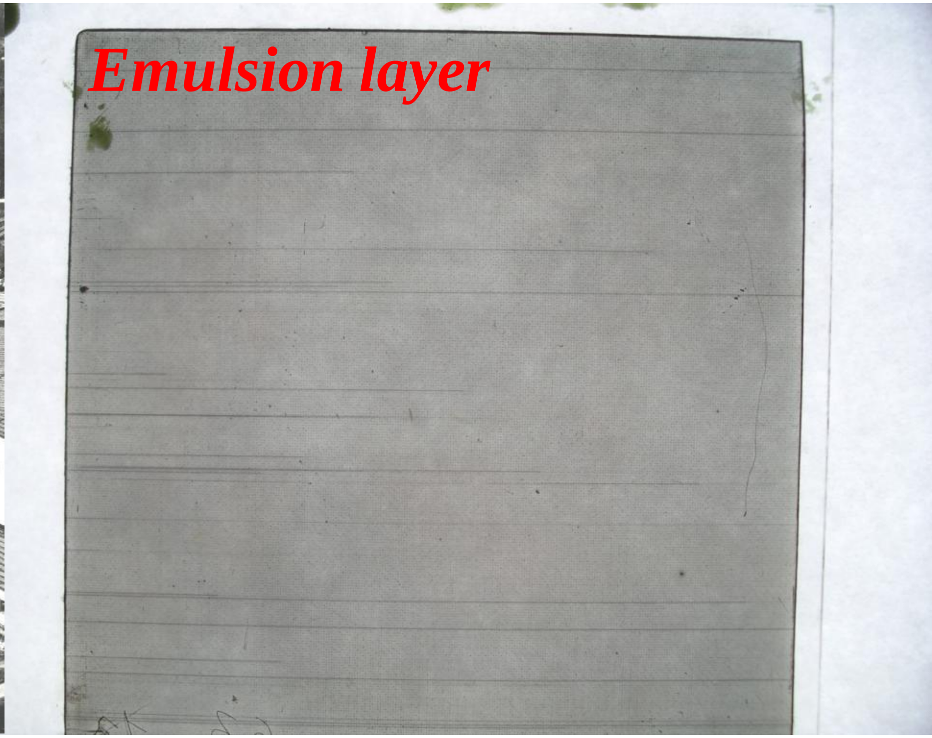
Introduction

Nuclear beams of energy higher than 1 A GeV are recognized as a modern tool used for the study of the structure of atomic nuclei*. Among the variety of nuclear interactions the peripheral dissociation beams a uniquely complete information about the excited states above particle decay thresholds. The peripheral dissociation is revealed as a narrow jet of relativistic fragments the summary charge of which is close to the charge of the primary nucleus. In spite of the relativistic velocity of motion the internal velocities in the jet are non-relativistic.

***T. Aumann, Eur. Phys. J. A, 26, 441(2005).**

BECQUEREL at the JINR Nuclotron is devoted systematic exploration of clustering features of light stable and radioactive nuclei.





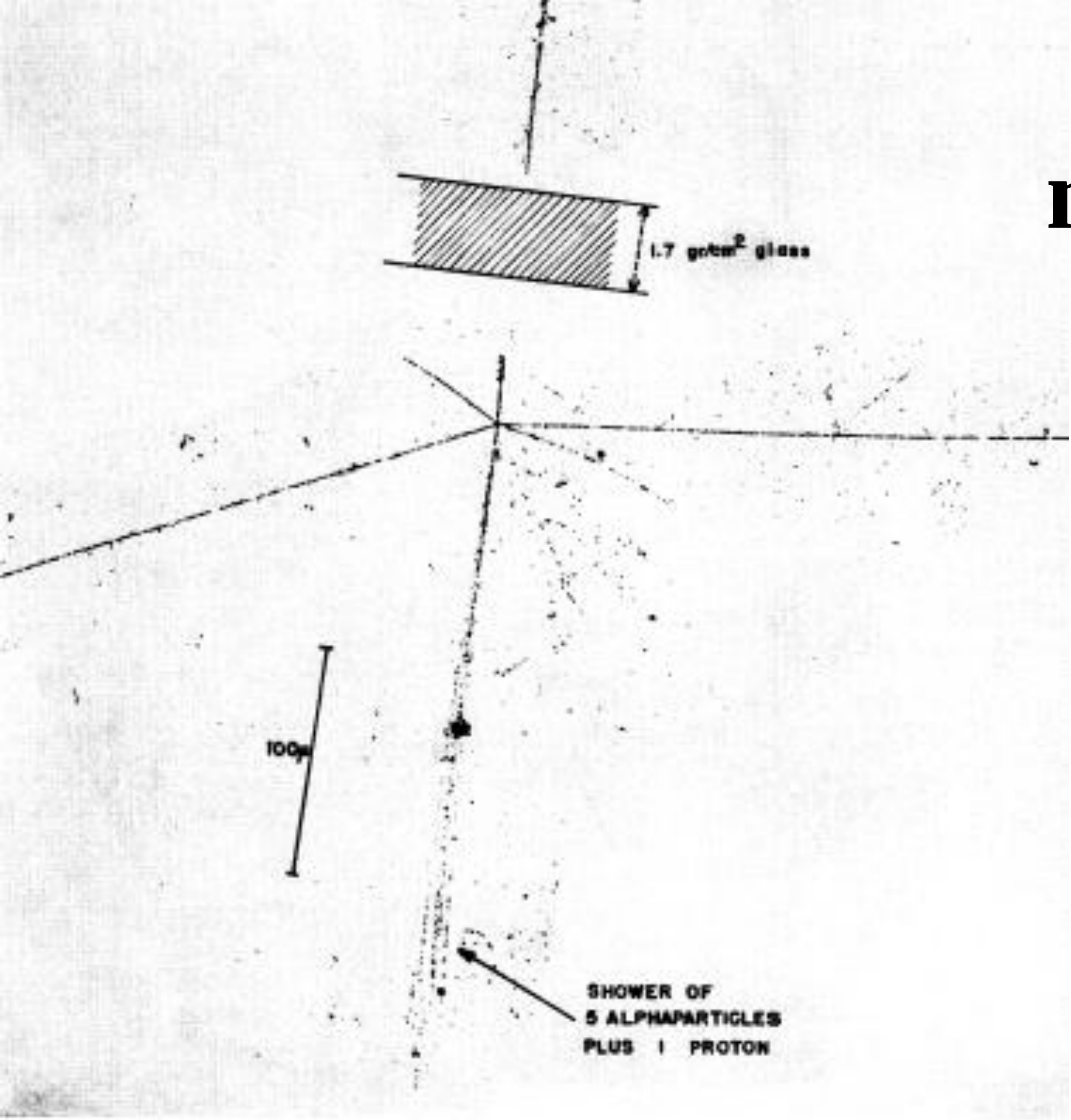
The fragmentation of a large variety of light nuclei was investigated using the emulsions exposed to few A GeV nuclear beams at JINR Nuclotron. A nuclear track emulsion is used to explore the fragmentation of the relativistic nuclei.

BR-2	10^{22} cm^{-3}
Ag	1.0
Br	1.0
C	1.4
N	0.4
O	1.1
H	3.0

0.5 µm resolution, identification of charges and H&He isotopes

The emulsion technique provides a record spatial resolution and allows one to observe the 3D images of peripheral collisions. The analysis of the relativistic fragmentation of neutron-deficient isotopes has special advantages owing to a larger fraction of observable nucleons.

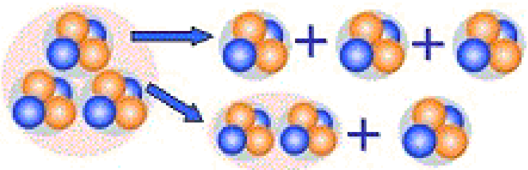
Collision of a nucleus of the Mg-Si group (Z~12-14)*

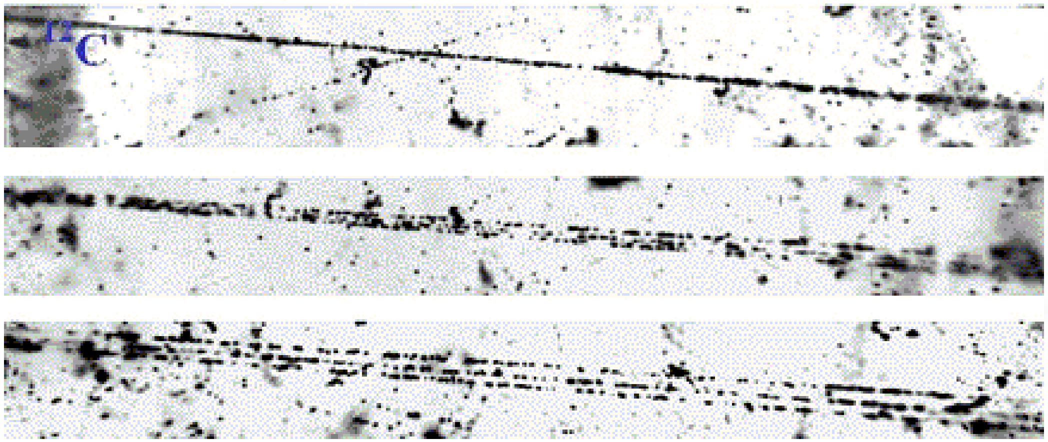


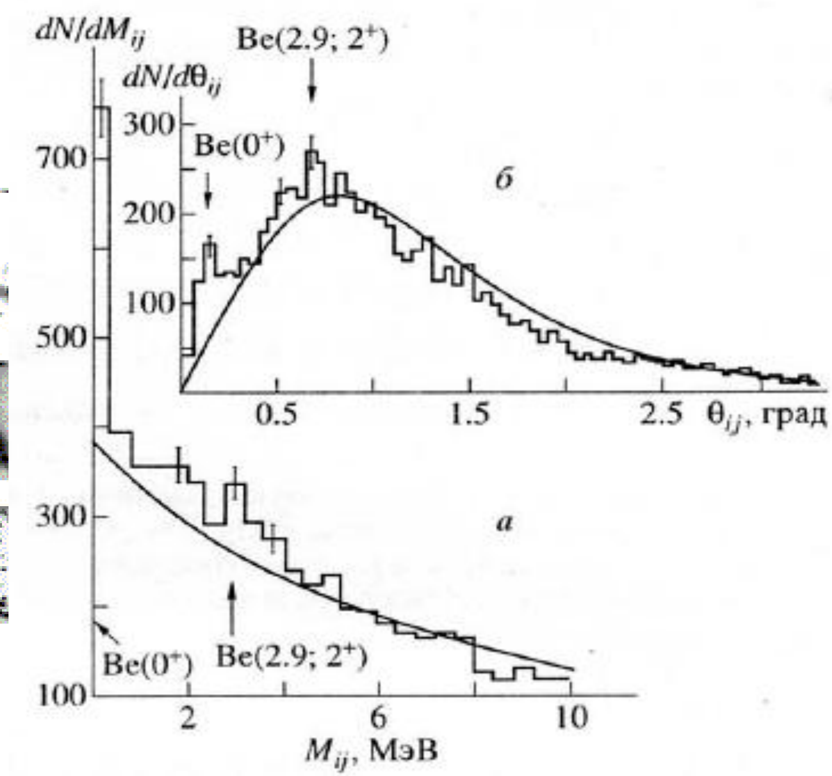
*H.L. Bradt and B. Peters, Phys. Rev. 77 (1950).

The $^{12}C \to 3\alpha$ and $^{16}O \to 4\alpha$ fragmentation at the energy of 3.65 A GeV was studied at JINR Synchrophasotron* .

$^{12}C \to 3\alpha$, 3.65 A GeV





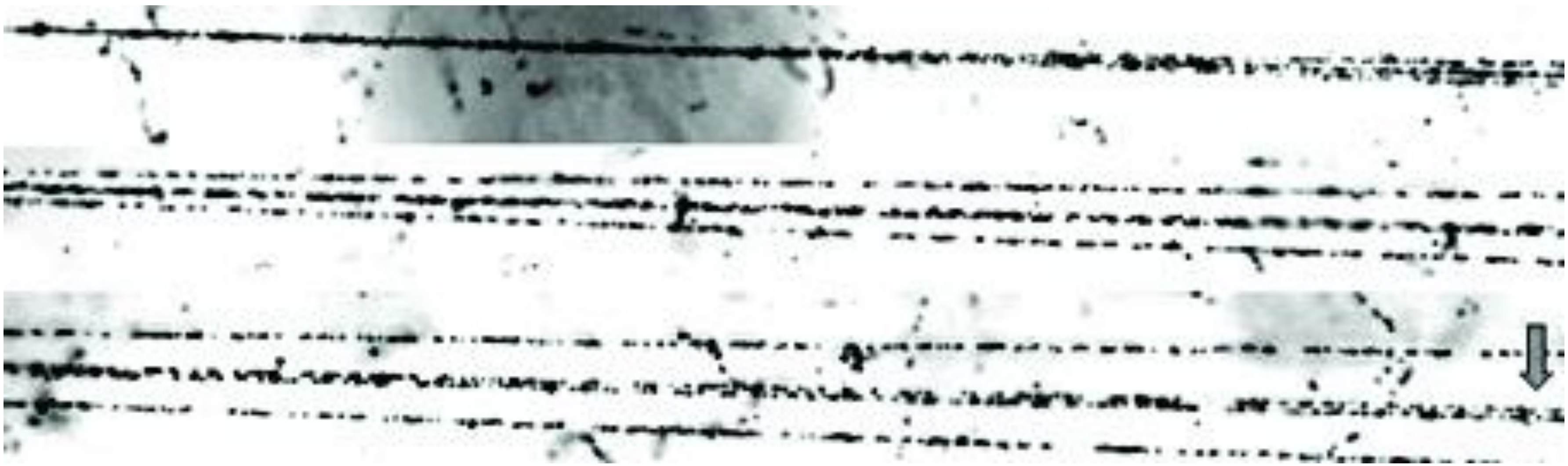


(PAVICOM image)

***V.V. Belaga et al., Phys. At. Nucl., vol. 58 (1995).**

The $^{16}O \to 4\alpha$ fragmentation were investigated using a large amount of information (641 events). An analysis of the angular correlations gave evidence that the angular momentum was transferred to the systems of fragments and that the cascade decays via ^{8}Be and ^{12}C nuclei were nonessential*.

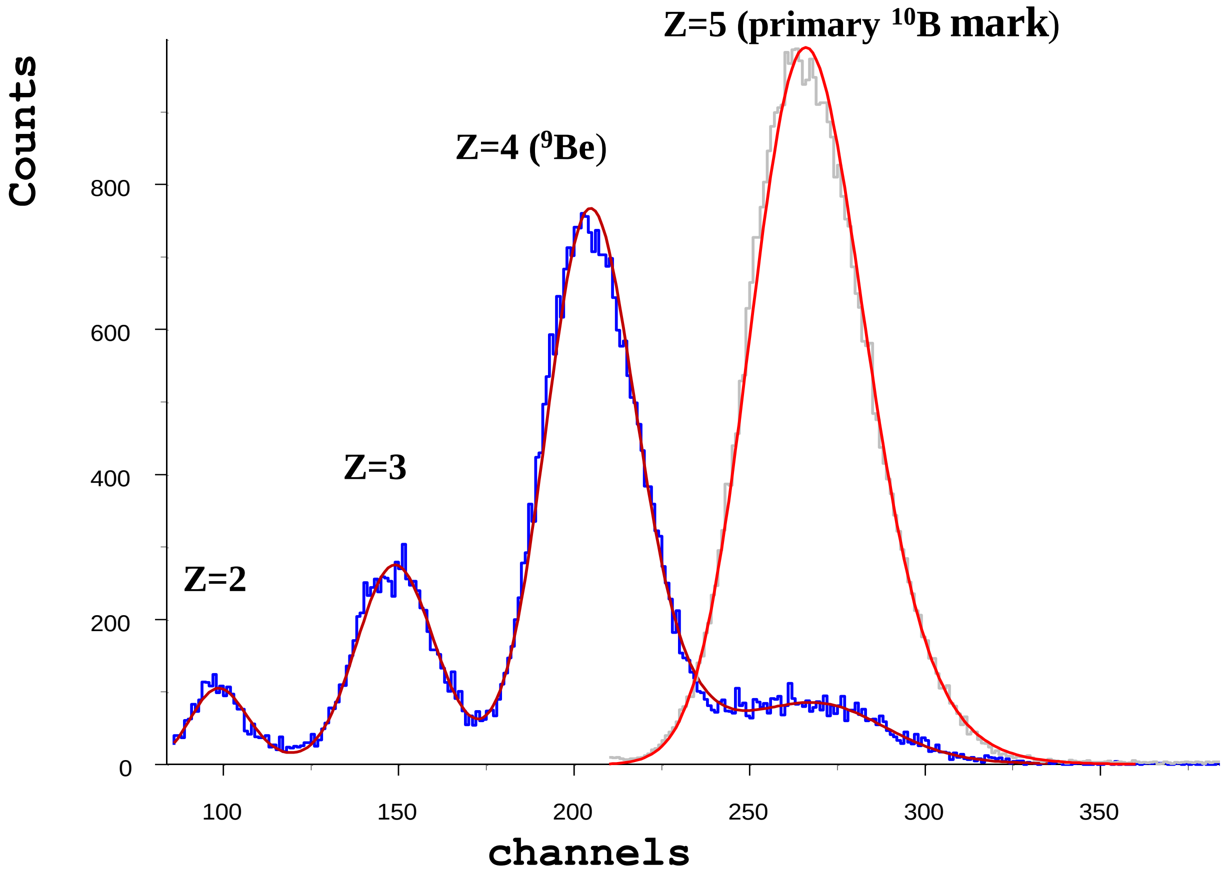
$^{16}O \to 4\alpha$, 3.65 A GeV **(PAVICOM image)**



***F.A. Avetyan et al., Phys. At. Nucl., vol. 59 (1996).**

Fragmentation of relativistic ^9Be nuclei at 1.2 A GeV

The beam of relativistic ^9Be nuclei was obtained in the $^{10}B \to {}^9Be$ fragmentation reaction with polyethylene target (JINR Nuclotron).



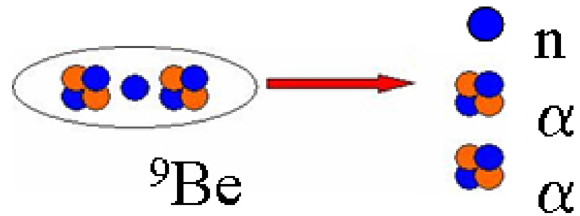
^9Be <u>fraction in the beam</u>:

67 2 %*

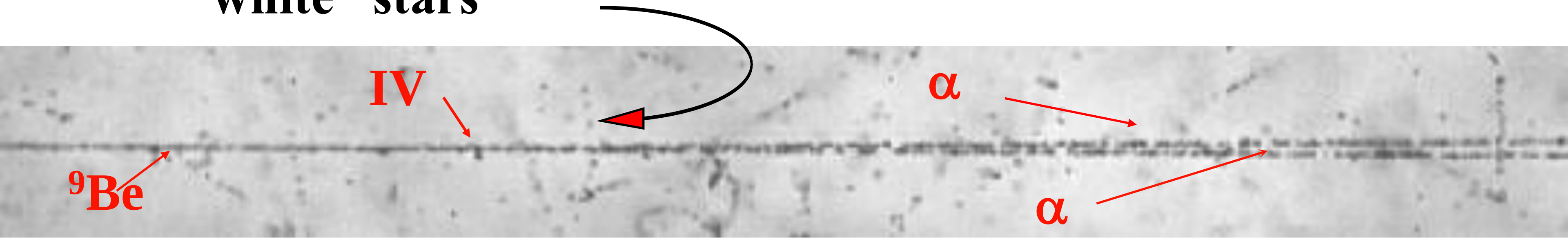
Found: 362 events of $^9Be \to 2\alpha$ fragmentation

Angular measurements accuracy not worse then 4.4×10^{-3} rad.

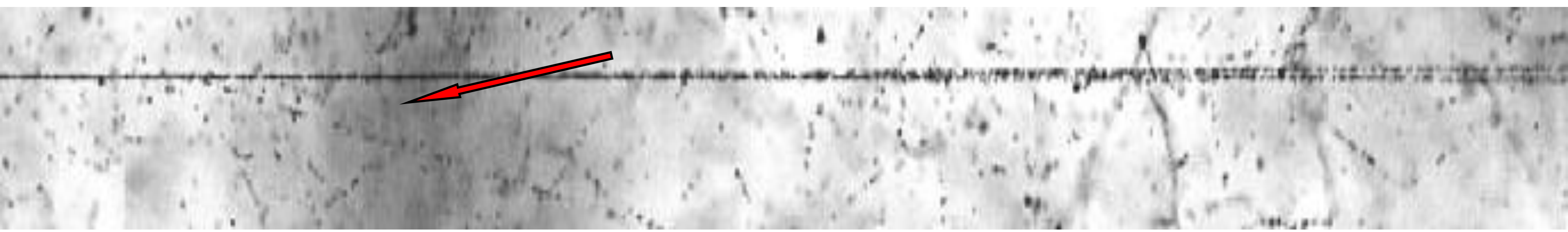
***today at 12.50: P.A. Rukoyatkin «Secondary fragment beams for studies of light nuclei structure using the emulsion technique at the LHEP facilities».**



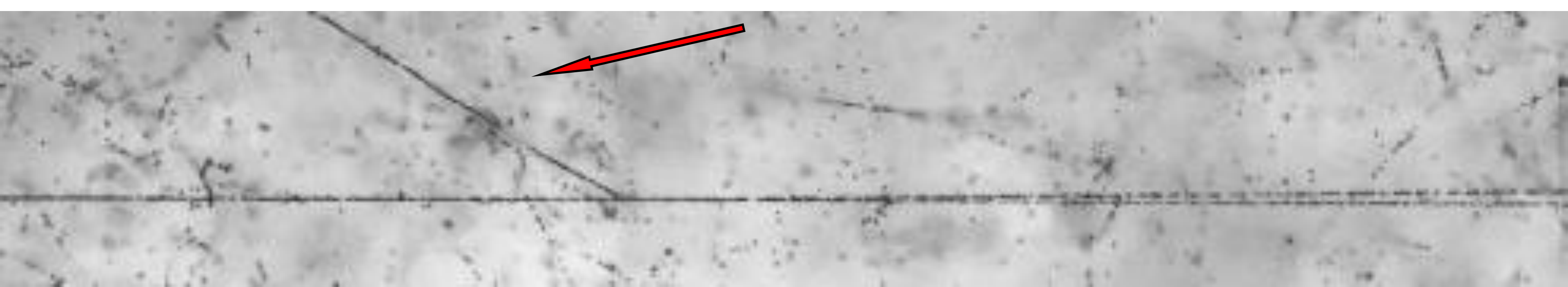
"white" stars



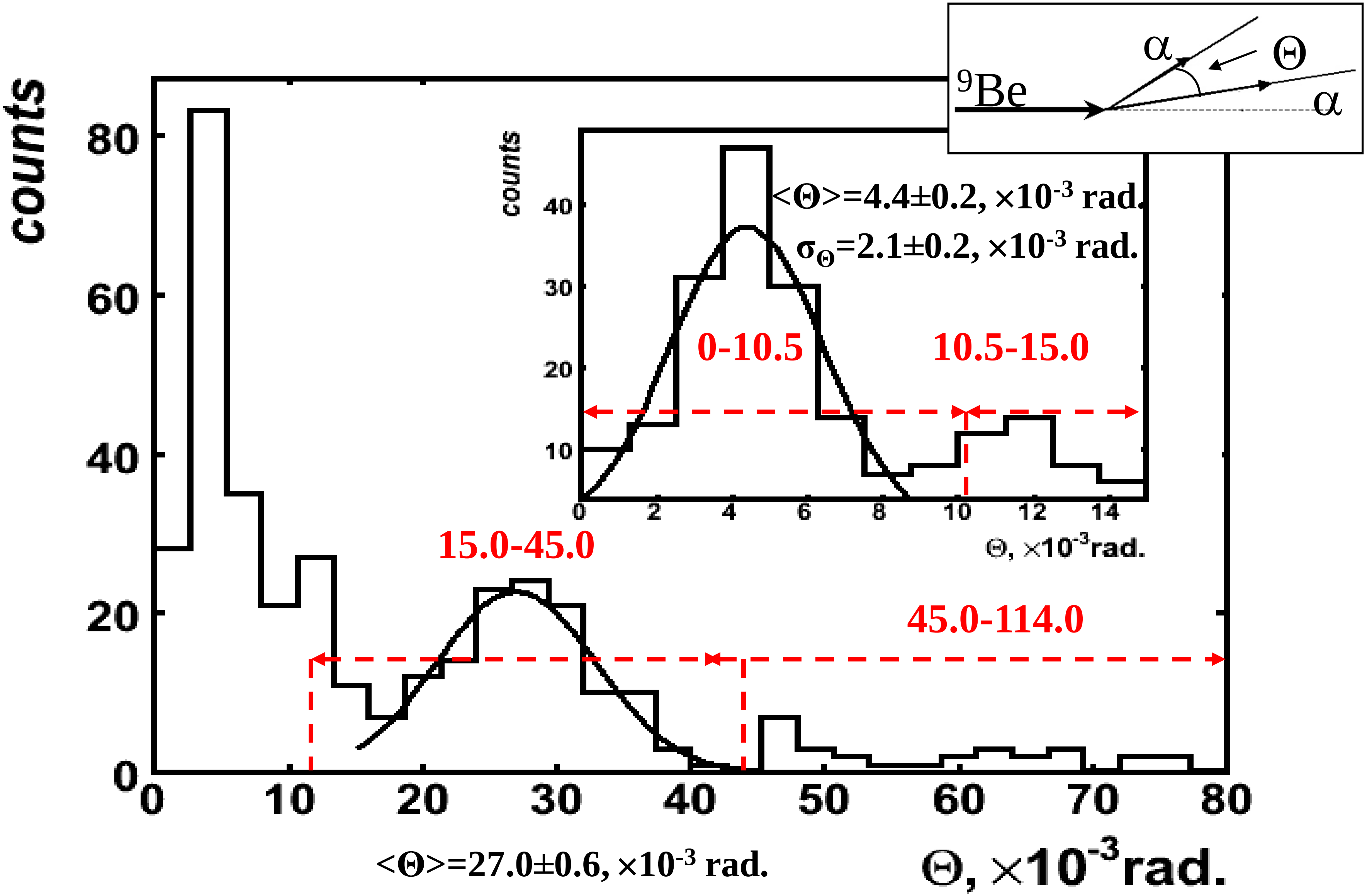
stars with target proton recoil (g-particle)



stars with heavy fragment of target nucleus (b-particle)



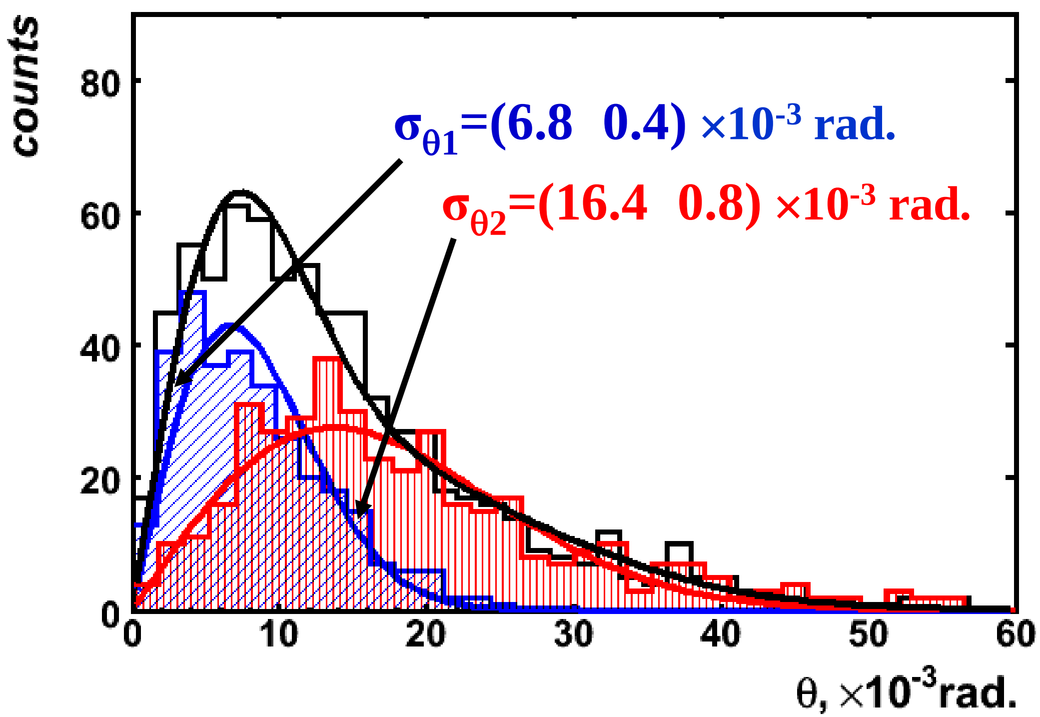
Opening angle Θ between two α fragments for $^{9}Be \rightarrow 2\alpha$

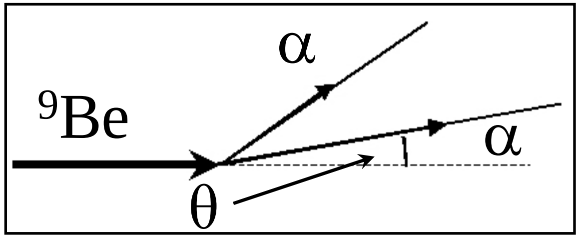


$\langle\Theta\rangle = 27.0 \pm 0.6$, $\times 10^{-3}$ rad.

$\sigma_{\Theta} = 5.9 \pm 0.6$, $\times 10^{-3}$ rad.

Polar angles θ of α fragments for $^9Be \rightarrow 2\alpha$





$$f(\theta) = \frac{\theta}{\sigma^2} \exp\left(\frac{-\theta^2}{2\sigma^2}\right)$$

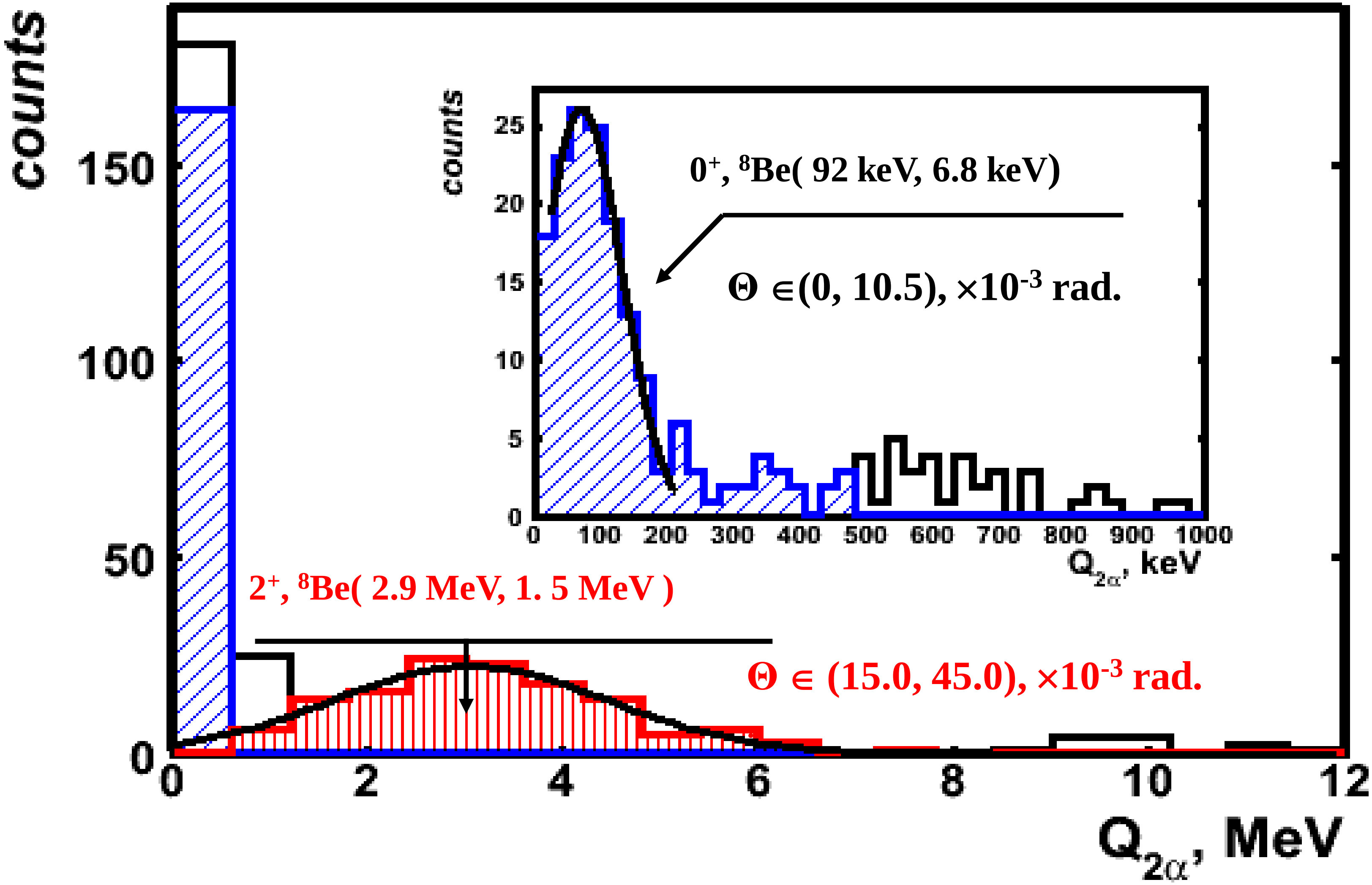
$$\sigma^2 = \frac{\sum_{i=1}^{N} \theta_i^2}{2N}$$

events with opening angles Θ ∈ (0, 10.5) ×10⁻³ rad.;

events with opening angles Θ ∈ (10.5, 114.0) ×10⁻³ rad.

$$M_{2\alpha} = \left[2\left(m_\alpha^2 + E_{\alpha 1}E_{\alpha 2} - p_{\alpha 1}p_{\alpha 2}\cos(\Theta_{12})\right)\right]^{\frac{1}{2}}$$

$$Q_{2\alpha} = M_{2\alpha} - 2 \cdot m_\alpha$$



The target dependence of $^9Be \to 2\alpha$ fragmentation

AgBr H CNO+AgBr

$n_g=0$ $n_b=0$	$n_g=1$ $n_b=0$	$n_g=0$ $n_b=3$	$n_g=0$ $n_b=4$	$n_g=0$ $n_b=5$	$n_g=0$ $n_b=6$	$n_h>2$ ($ng \neq 0$)	…	Number of events
176	33	9	9	2	1	43	…	362

$$W_{ti} = \pi \cdot R_0^2 \cdot \left(A_t^{\frac{1}{3}} + A_i^{\frac{1}{3}} - 1.17 \right)^2, \; R_0 = 1.45 \; fm$$

Target nucleus	P, %	W (^{9}Be-Em), (BR-2), %
H	9 2	10.4
CNO+AgBr	91±7	89.6

The results comparison of $^9Be \to 2\alpha$, $^{12}C \to 3\alpha$, $^{16}O \to 4\alpha$ fragmentation in nuclear track emulsion

Parameter	^{9}Be (BR-2), $^9Be \to 2\alpha$	^{12}C (BR-2), $^{12}C \to 3\alpha$	^{12}C (BR-2+Pb), $^{12}C \to 3\alpha$	^{16}O (BR-2), $^{16}O \to 4\alpha$
number of events	362	44	72	641
$\langle P_T^2 \rangle^{1/2}$, MeVc	148 6 74 4, $\Theta \in (0,10.5)$ mrad., 156 9, $\Theta \in (15.0,45.0)$ mrad., 177 8, $\Theta \in (10.5, 114.0)$ mrad.	192 10	161 6	167 4
$\langle P{*}_T^2 \rangle^{1/2}$, MeV/c	98 4 20 2, $\Theta \in (0,10.5)$ mrad., 105 9, $\Theta \in (15.0,45.0)$ mrad., 130 9, $\Theta \in (10.5, 114.0)$ mrad.	141 7	130 8	145 3
kT, MeV	2.6 ≈0.11, $\Theta \in (0,10.5)$ mrad., 3.0, $\Theta \in (15.0, 45.0)$ mrad., 4.5, $\Theta \in (10.5, 114.0)$ mrad.	4.0	3.4	3.7

$$*kT = \frac{A \cdot \langle P_T^{*2} \rangle}{2 \cdot A_F (A - A_F) \cdot m_N}$$

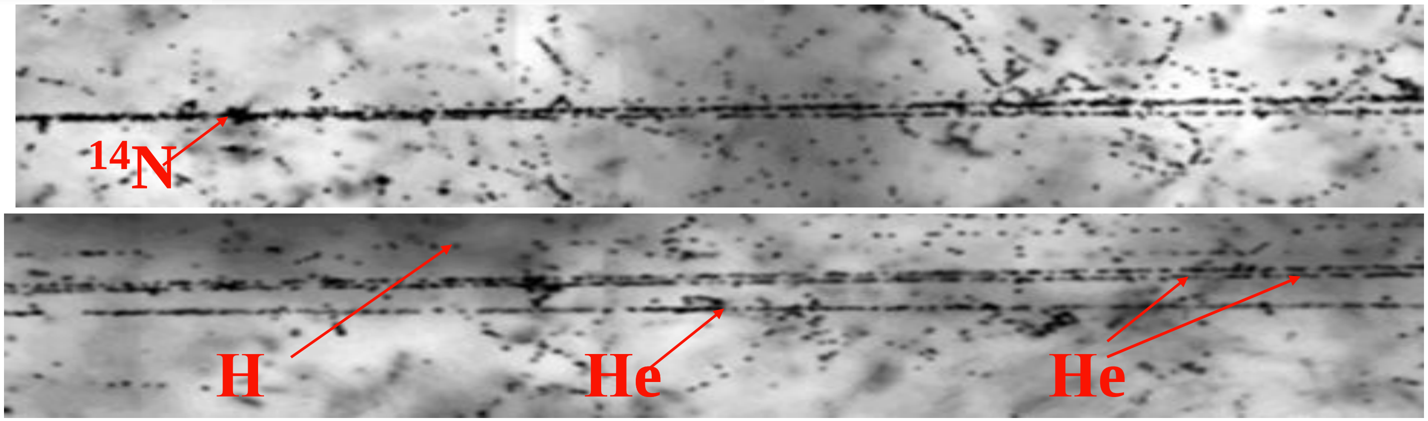
*F.A. Avetyan, et al., Phys. At. Nucl. 59 (1996)

…summary

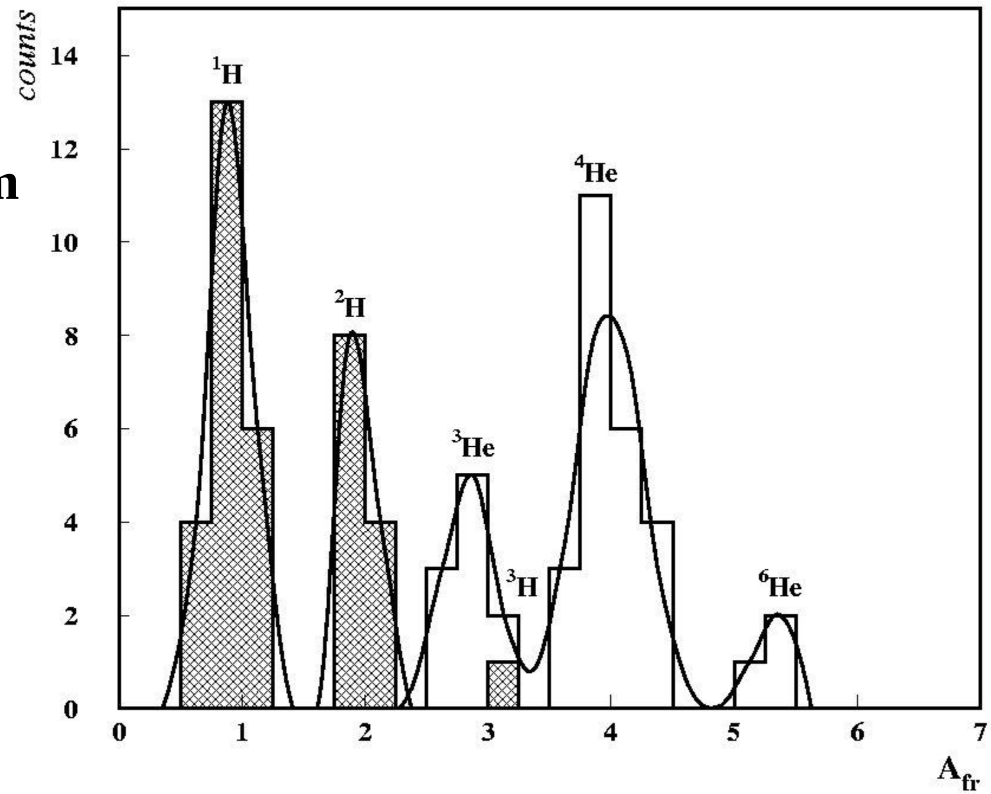
1) **In the first time the properties of ^9Be like 2α +n system is studied in peripheral fragmentation in nuclear track emulsion with relativistic energies, using the Nuclotron of JINR.**
2) **The results obtained in a large (for emulsion experiments) statistics – 362 events of $^9Be \to 2\alpha$ peripheral fragmentation on H, CNO, AgBr. The achieved accuracy of angular measurements not worse then $4.4 \quad 10^{-3}$ rad.**
3) **In peripheral interactions the ^9Be nuclei are dissociated practically totally through the 0^+ and 2^+ states of the ^8Be nucleus.**
4) **The data obtained from ^9Be investigation can be employed for the estimation of the ^8Be role in more complicated $N\alpha$ systems.**

Fragmentation of relativistic ^{14}N nuclei at 2.1 A GeV

Experiment: N_Σ = 951 inelastic interaction (123.71 m); λ = *13.0 0.4* cm



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



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

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

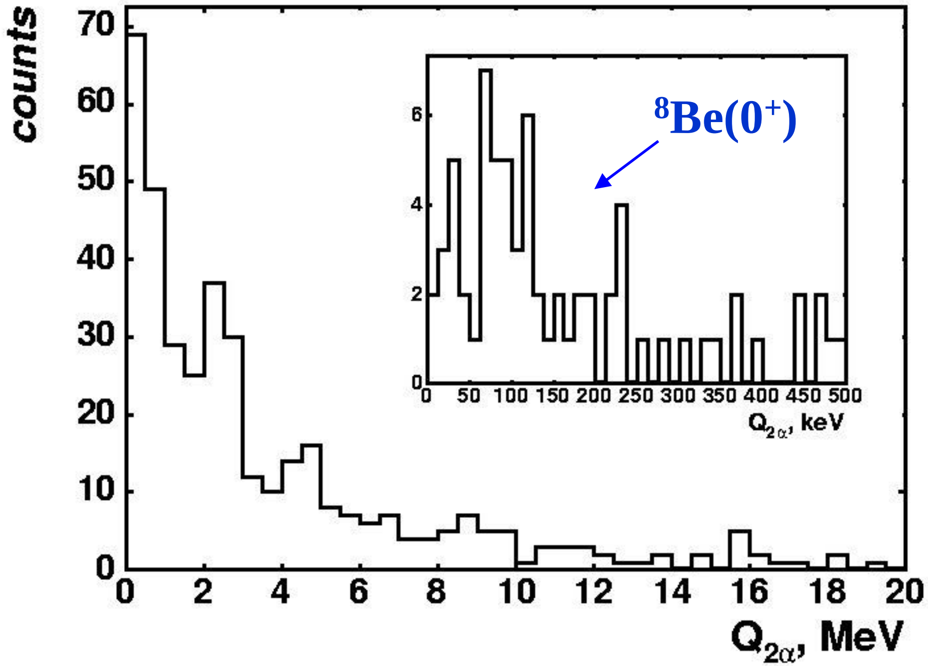
$$^{10}B \longrightarrow \frac{2He + p}{2He + d} \cong 1$$

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

^{6}Li→ ЯФ 62, №8, с. 1461-1471, (1999)

^{10}B →ЯФ 66, №9, с. 1694-1698, (2003)

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

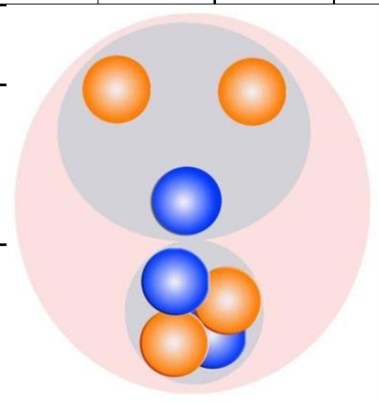


*today at 12.30: T. Shchedrina «Clustering features of ^{14}N in relativistic multifragmentation process».

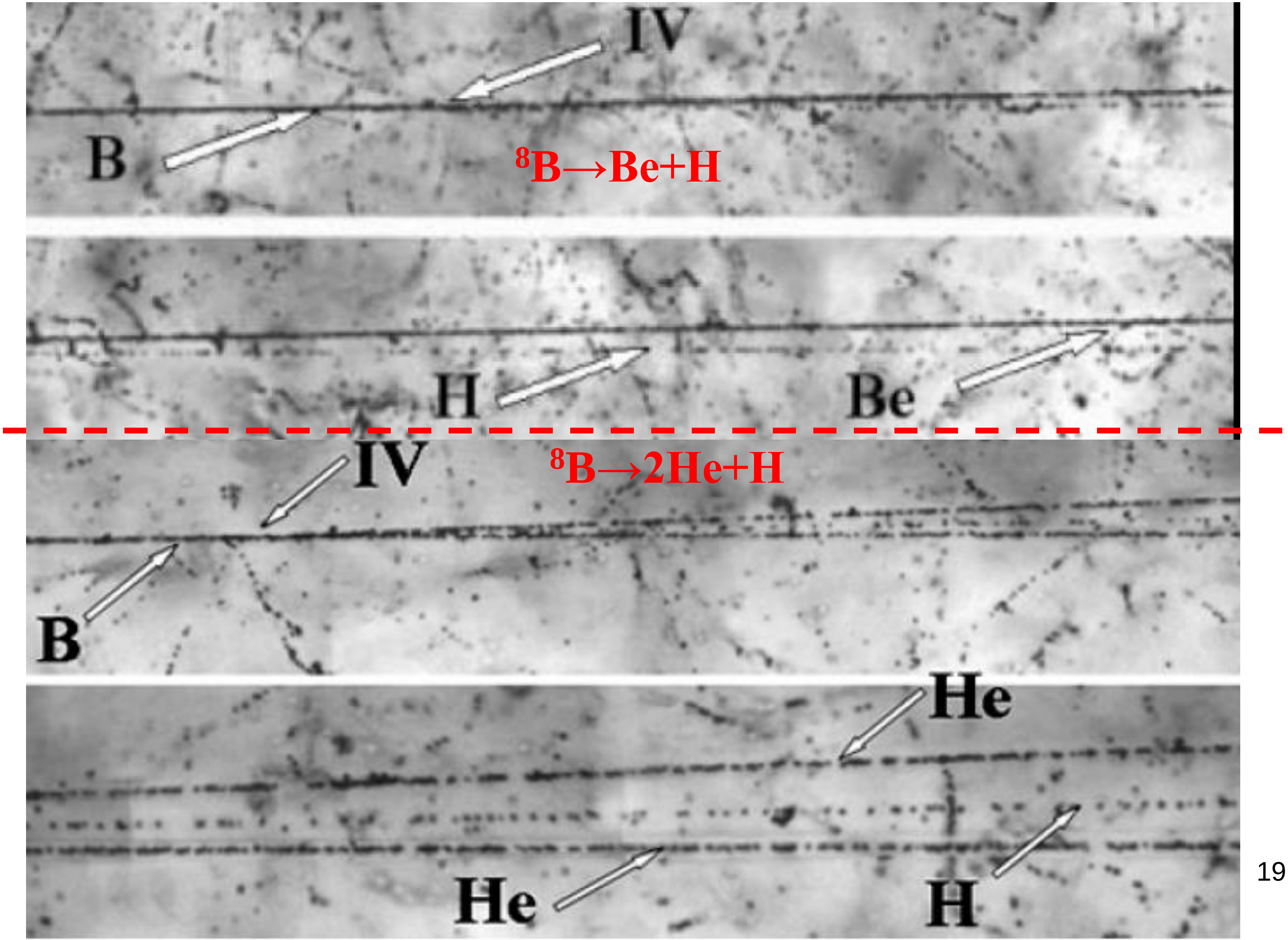
Fragmentation of relativistic ^{7}Be nuclei at 1.2 A GeV

TABLE III: ^{7}Be fragmentation channel (number of events)

MeV	Channel	2He	2He	He+2H	He+2H	4H	4H	Li+H	Li+H	Sum
		$n_b = 0$	$n_b > 0$	$n_b = 0$	$n_b > 0$	$n_b = 0$	$n_b > 0$	$n_b = 0$	$n_b > 0$	
1.6	$^{3}He+^{4}He$	30	11							41
22.1	$^{3}He+^{3}He$	11	7							18
	$^{4}He+2p$			13	9					22
7.1	$^{4}He+d+p$			10	5					15
	$^{3}He+2p$			9	9					18
28.0	$^{3}He+d+p$			8	10					18
	$^{3}He+2d$			1						1
21.0	$^{3}He+t+p$			1						1
	$3p+d$					2				2
	$2p+2d$					1				1
5.6	$^{6}Li+p$							9	3	12
	Sum	41	18	42	33	2	1	9	3	149



Fragmentation of relativistic ^{8}B nuclei at 1.2 A GeV



^{8}B fragmentation channel (number of events)

ΣZ_{fr}	N_z					N_{ws}	N_{tf}	
	5	4	3	2	1			
5	-	-	-	1	3	12	42	He+3H
5	-	-	-	2	1	14	44	2He+H
5	-	-	1	-	2	-	5	Li+2H
5	-	-	1	1	-	-	2	Li+He
5	-	1	-	-	1	25	16	Be+H
5	1	-	-	-	-	1	13	
5	-	-	-	-	5	-	2	5H

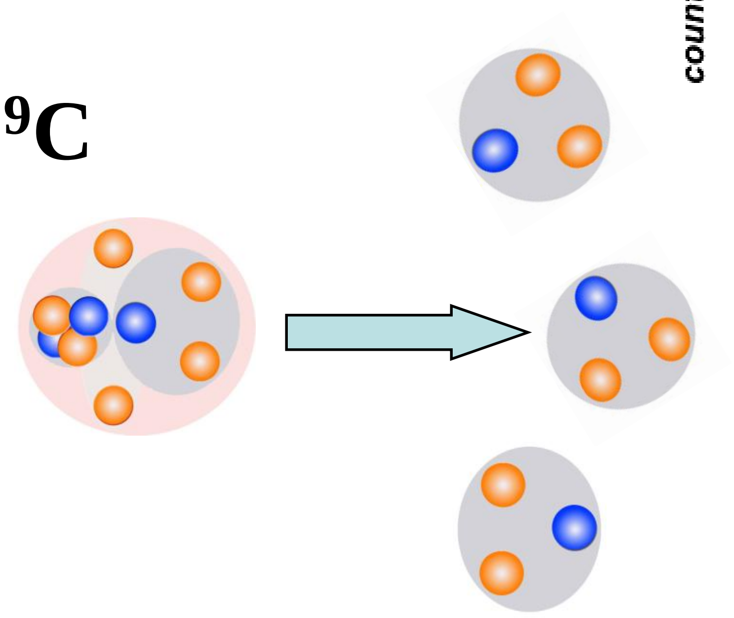
^{7}Be: N. G. Peresadko et al., Phys.At.Nucl. 58, 1226 (2007).
^{8}B: R. Stanoeva et al., Phys.At.Nucl. 70, 1216 (2007).

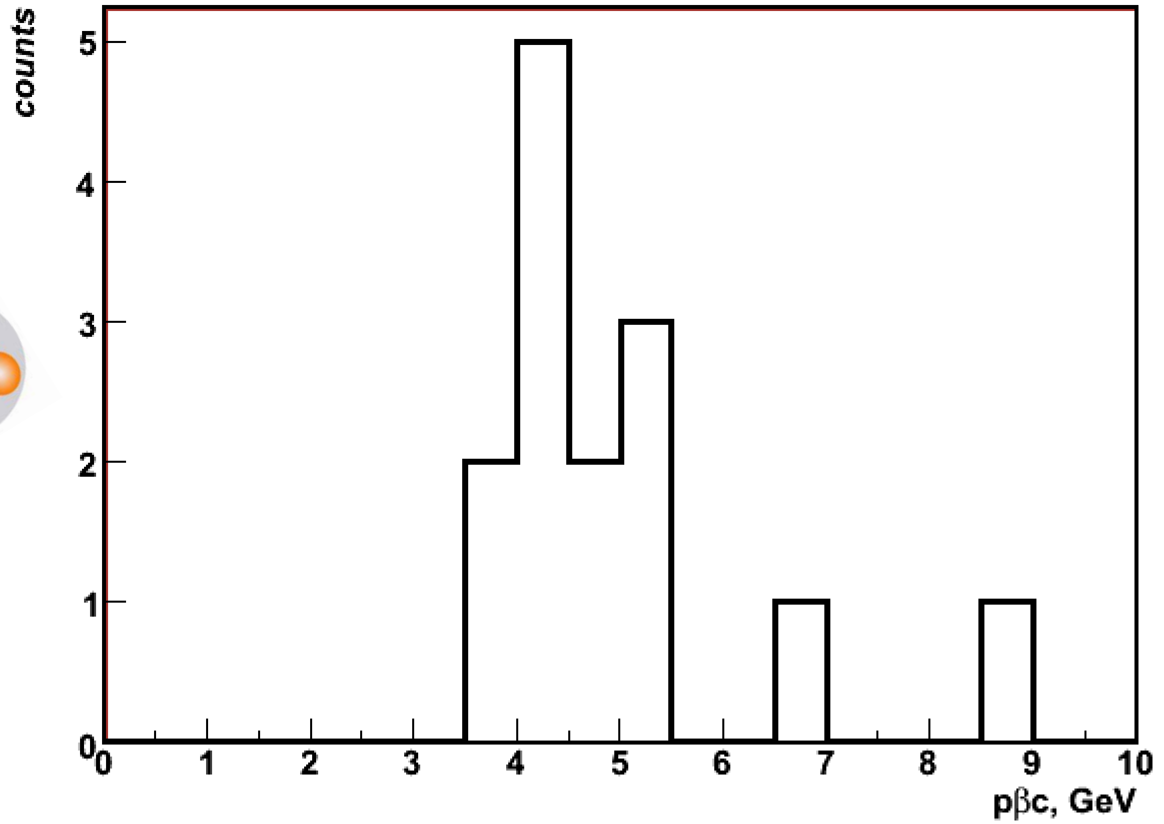
Fragmentation of relativistic ^{9}C nuclei at 1.2 A GeV

The charge topology distribution of the “white” stars

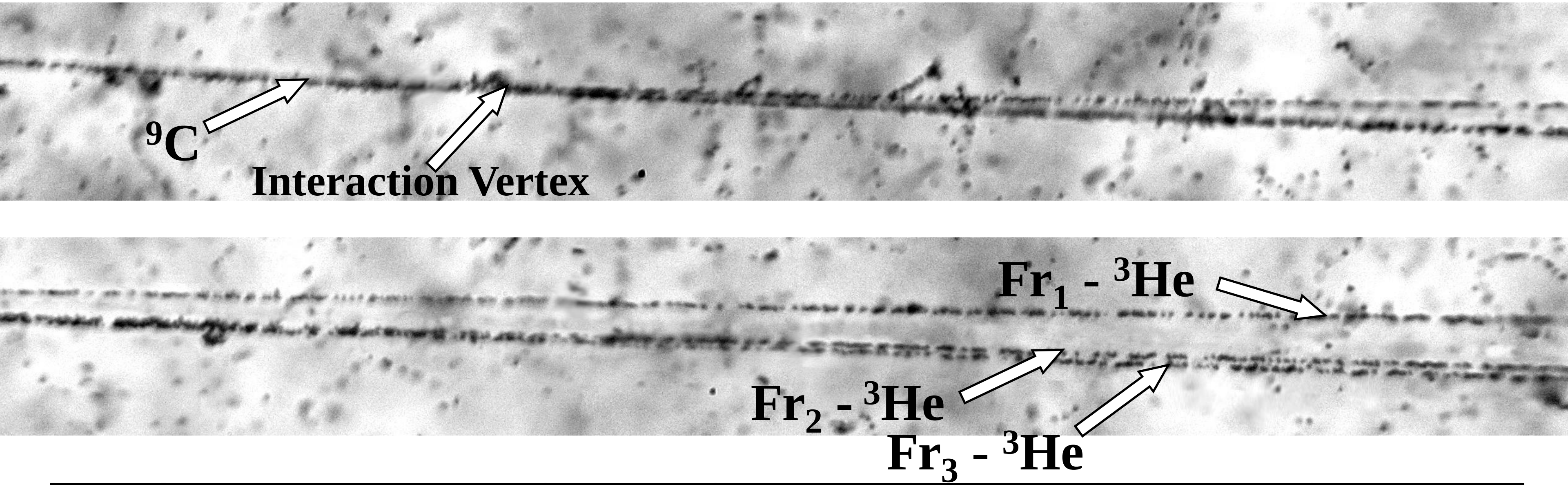
Z_{fr}	5	4	4	3	3	-	-	-	-
$N_{Z=1}$	1	2	-	1	3	-	4	2	6
$N_{Z=2}$	-	-	1	1	-	3	1	2	-
N_{ws}	11	16	1	2	2	13	22	21	1
$^{9}C \rightarrow$	B+H	Be+2H	Be+He	Li+He+H	Li+3H	3He	He+4H	2He+2H	6H

Double-charged fragments identification from $^9C_{ws} \rightarrow 3\,^3He$ using the multiple Coulomb scattering method



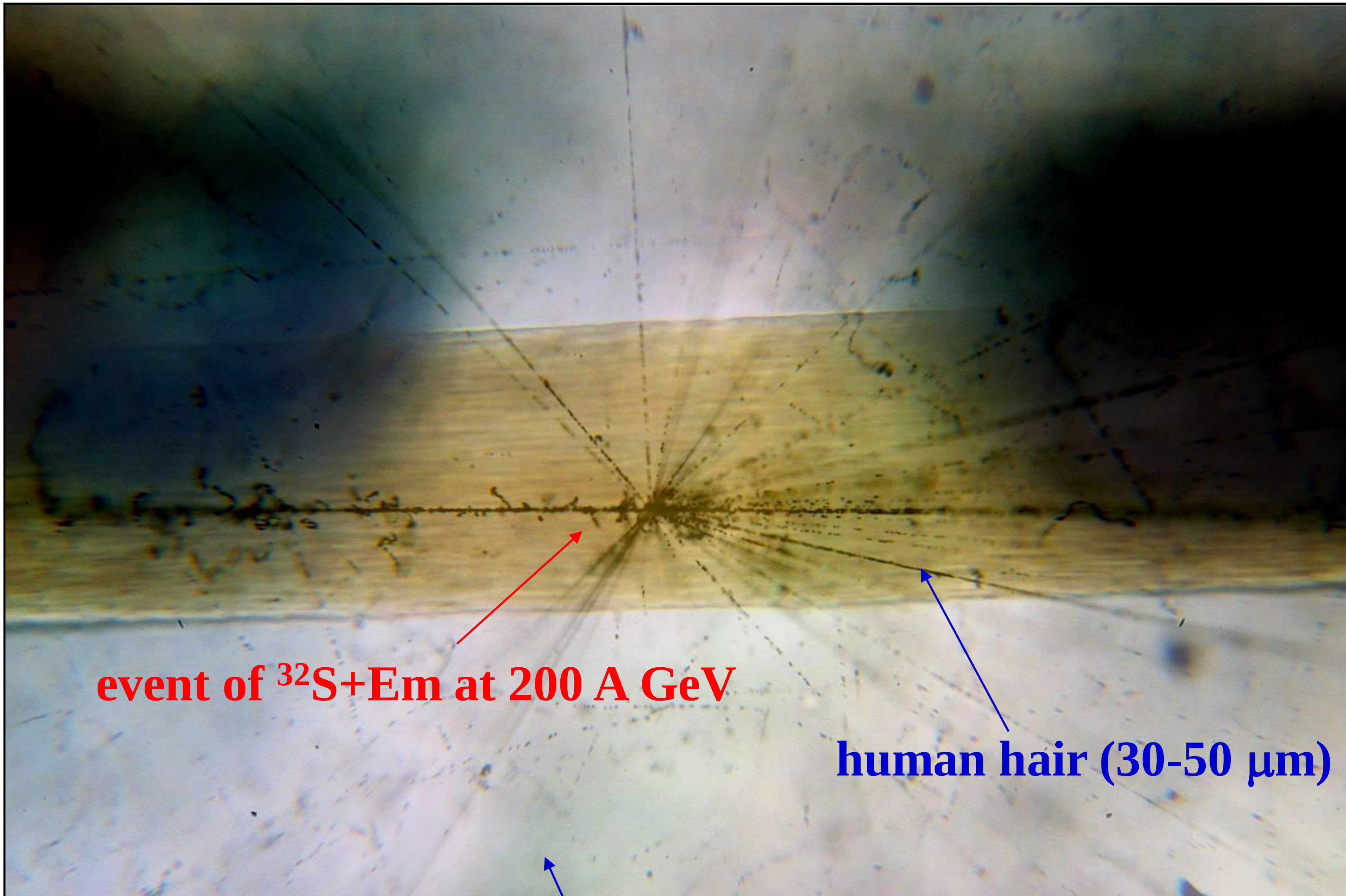


Fully identified event of $^{9}C \rightarrow 3\ ^{3}He$



	Opening angle $\Theta_{i,j}$ mrad	P_t, MeV	ΣP_t, MeV	P_t^*, MeV	$\varepsilon_{i,j}^*$, rad	$Q_{2^{3}He}$, MeV
Fr$_1$	56.0	466	760	216	3.038	0.046
Fr$_2$	55.0	154		111	3.034	8.786
Fr$_3$	4.0	148		106	0.211	9.017

Typical scales on emulsion plate & fragmentation of ^{32}S



E=200 A GeV (CERN/SPS, data of EMU01 collaboration)

N=1558 inelastic interactions* of ^{32}S+Em (on 2758 tracks)

The charge topology distribution of the ^{32}S+Em at 200 A GeV

ΣZ_{fr}	Z_{fr} ($n_s \neq 0$)			N $n_b=0, n_g=0$	N $n_b \neq 0, n_g \neq 0$
	≥ 3	2	1		
16	2	1	-	7	10
16	2	2	-	1 1(ns=0)	2
16	2	-	-	6	14
16	3	-	-	1	-
16	0	0	16	-	8
16	0	4	8	-	18
16	0	5	6	-	2

$n_f \neq 0$ (first four rows)

nHe+mH (last three rows)

*A.A. Moiseenko and V.R. Sarkisyan, Yerevan Physics Institute, Yerevan, Armenia

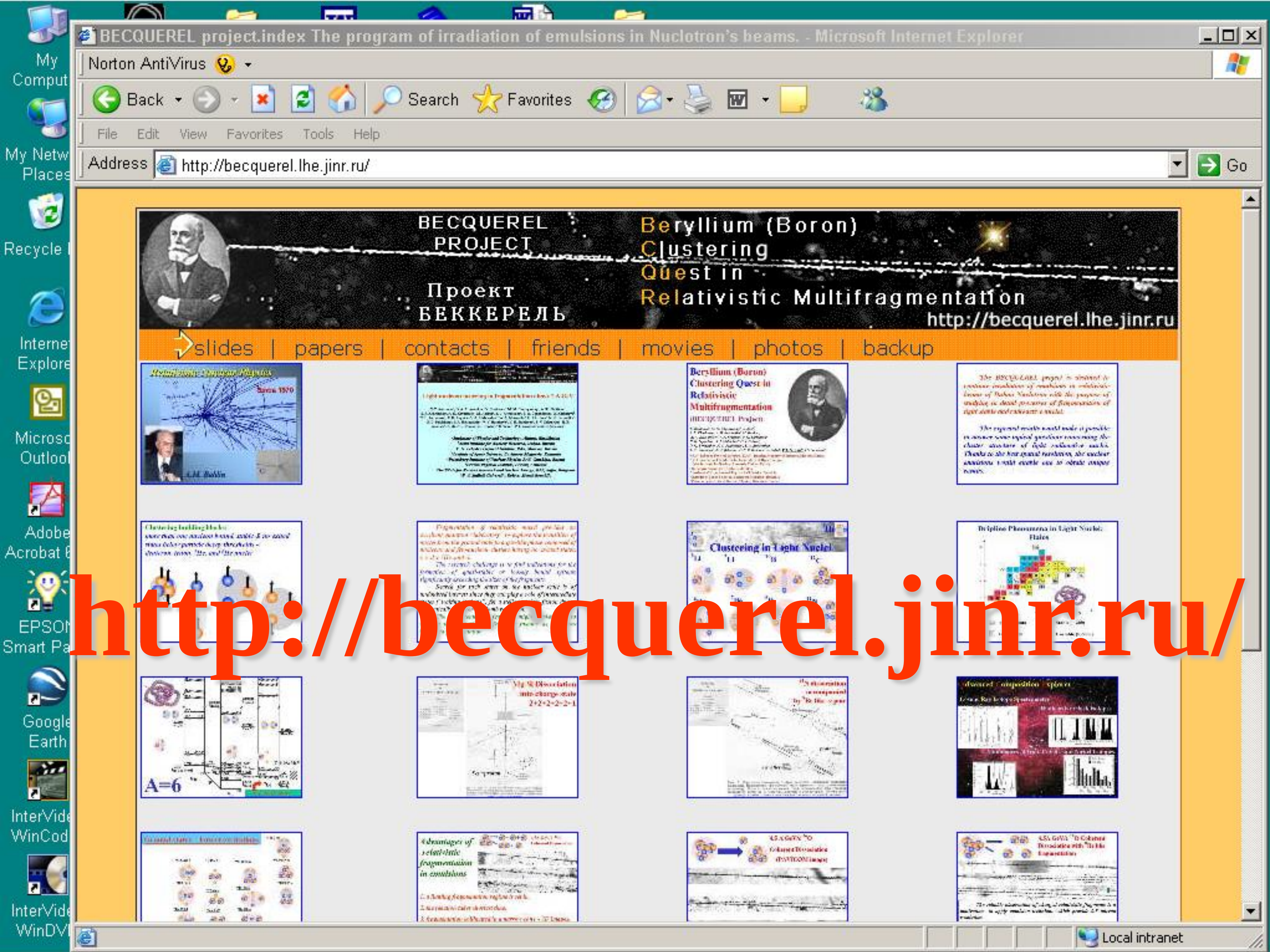
Concluding remarks

Due to a record space resolution the emulsion technique provides unique entirety in studying of light nuclei, especially, neutron-deficient ones.

In presented talk, we give the prospects and results of the study of ^{7,9}Be ,^{8}B, ^{9}C and ^{14}N nuclei, fragmentation with a few A GeV energy which are obtained with the use of a part of the material analyzed.

Providing the 3D observation of narrow dissociation vertices this classical technique gives novel possibilities of moving toward more and more complicated nuclear systems. Therefore this technique deserves upgrade, without changes in its detection basics, with the aim to speed up the microscope scanning for rather rare events of peripheral dissociation.

The presented observations serve as an illustration of prospects of the Nuclotron for nuclear physics and astrophysics researches.



http://becquerel.jinr.ru/