The Institute of Nuclear Physics
Ministry of Energy of the Republic of Kazakhstan

Joint Institute for Nuclear Research
SCIENCE BRINGING NATIONS TOGETHER

NATIONAL RESEARCH CENTER
"KURCHATOV INSTITUTE"

INVESTIGATION OF THE EXCITED STATES OF ^{11}B NUCLEUS

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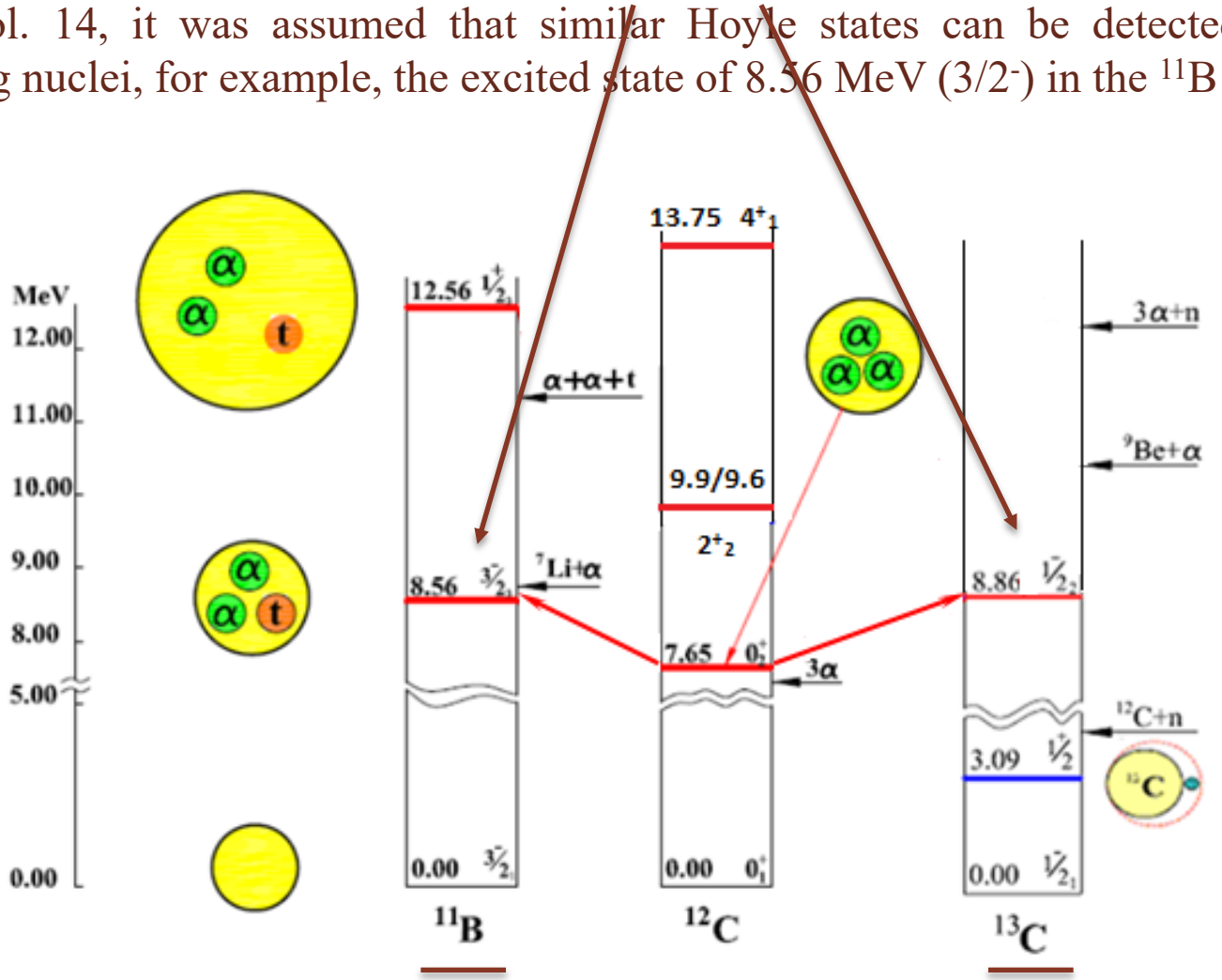
AYSS, DUBNA
2018

Relevance

Analogues of Hoyle's state

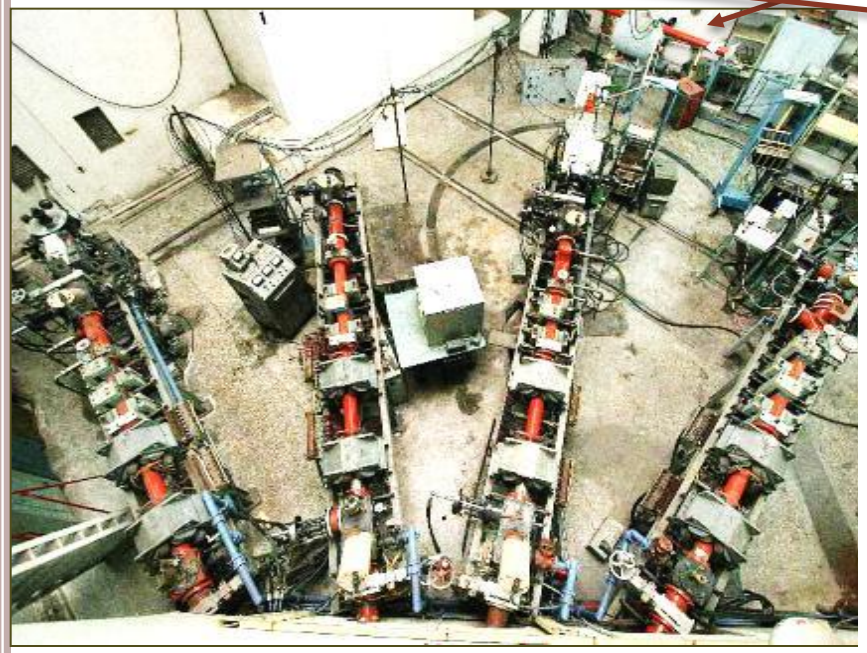
For nuclei with a pronounced cluster structure, the shell model does not reflect a number of their characteristic features. In the paper Milin M. and von Oertzen W // Eur. Phys. J. A-2002.-Vol. 14, it was assumed that similar Hoyle states can be detected in some neighboring nuclei, for example, the excited state of 8.56 MeV ($3/2^-$) in the ^{11}B nucleus.

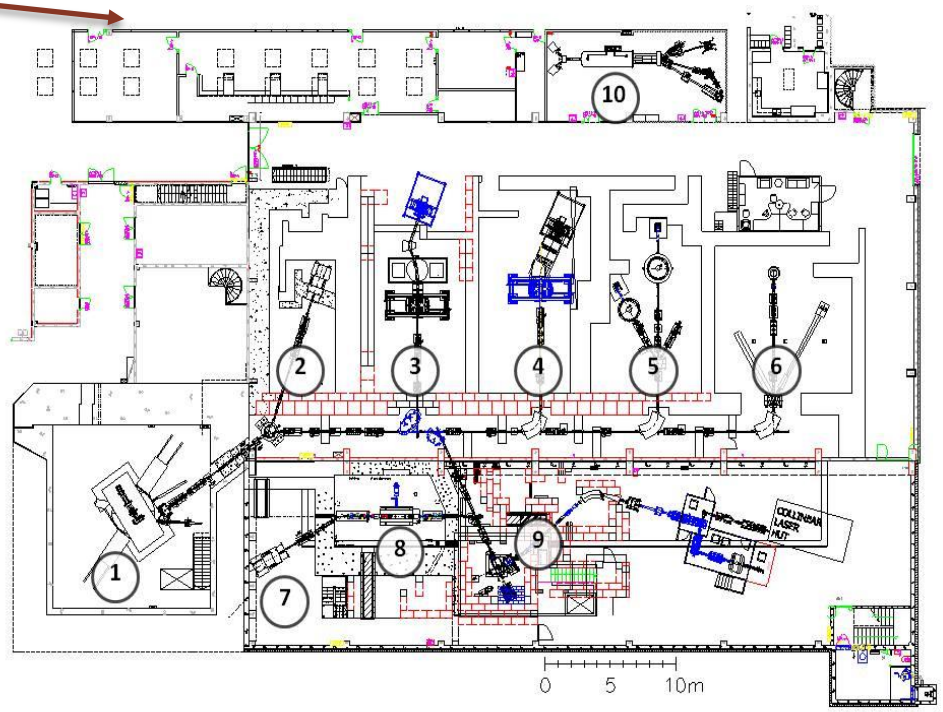


Experiment

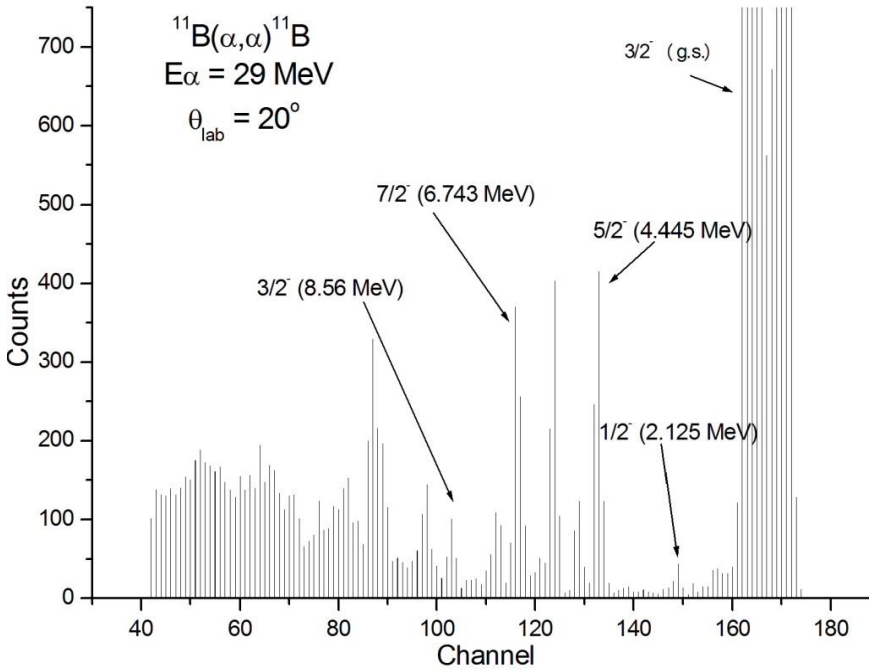
A series of collaborative experiments were conducted with the scientists of the Kurchatov Institute (Moscow, Russia) and the University of Jyväskylä (Jyvaskyla, Finland) in order to study the "exotic" state in neutron-rich nuclei (^{9}Be, ^{11}B, and ^{13}C), .

Experiments were carried out on the cyclotrons **U150M** (INP, Kazakhstan) and **K-130** (UY, Finland) at energies of accelerated alpha particles E(α) = 29 and 65 MeV, respectively.

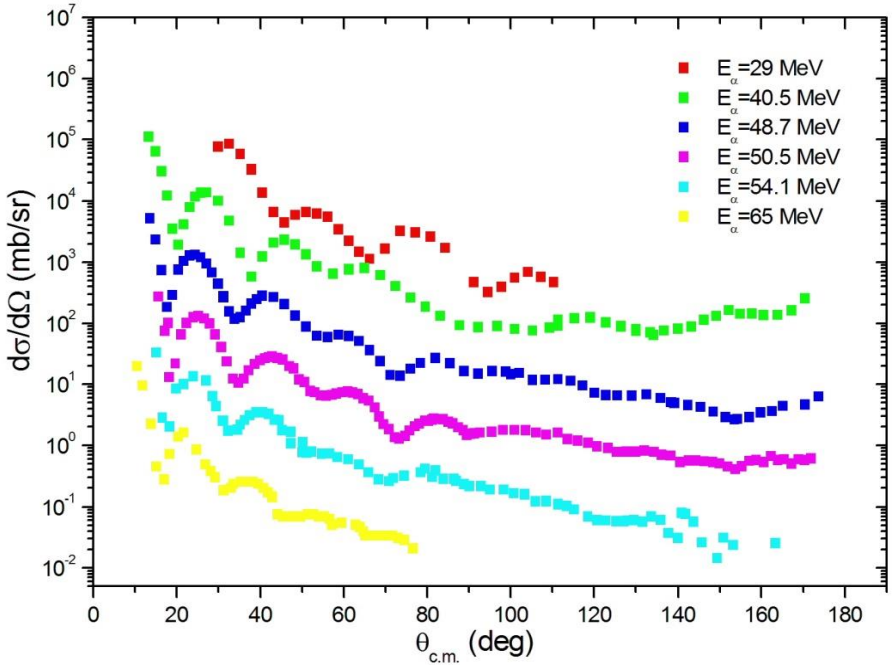




Experiment



Energy spectra of alpha particles scattered from ^{11}B at 20 degrees in laboratory frame, E_α=29 MeV.



Differential cross sections of elastic scattering of alpha particles from ^{11}B at different energies of incident particles

Theory

In the frame of the **optical model**, all the interactions between the nucleons of the projectile and the nucleons of the target are replaced by an average and central interaction *U(r)* between the projectile and the target in their ground states.

$$\Delta\Psi + \frac{2\mu}{\hbar^2}\left(E - U(r)\right)\Psi = 0$$

$$U(r) = V_C(r) - V(r) - iW_V(r).$$

The complex potential *U(r)* used in the optical model

$$U(r) = V_c(r) - V_o\left[1 + \exp\left(\frac{r - r_V.A^{1/3}}{a_V}\right)\right]^{-1} - iW_o\left[1 + \exp\left(\frac{r - r_W.A^{1/3}}{a_W}\right)\right]^{-1},$$

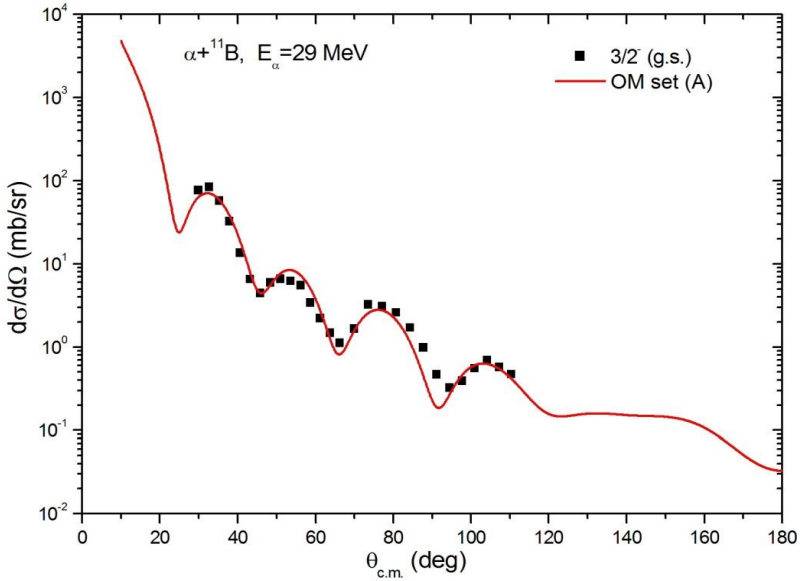
$$V(r) = \iint \rho_p(r_p)\rho_t(r_t)\upsilon(r_{tp})d^3r_p d^3r_t$$

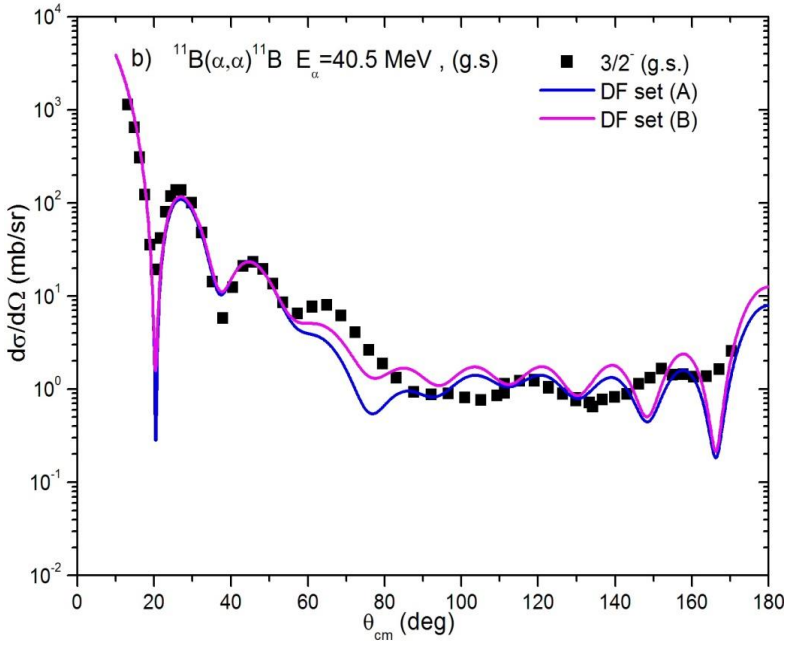
The **double folding** (DF) model was widely used with success to calculate the nucleus-nucleus interaction potential or the nucleon-nucleus interaction potential.

The parameters of optical and double folding potentials of $\alpha + {}^{11}B$ system at 29 – 54.1 MeV

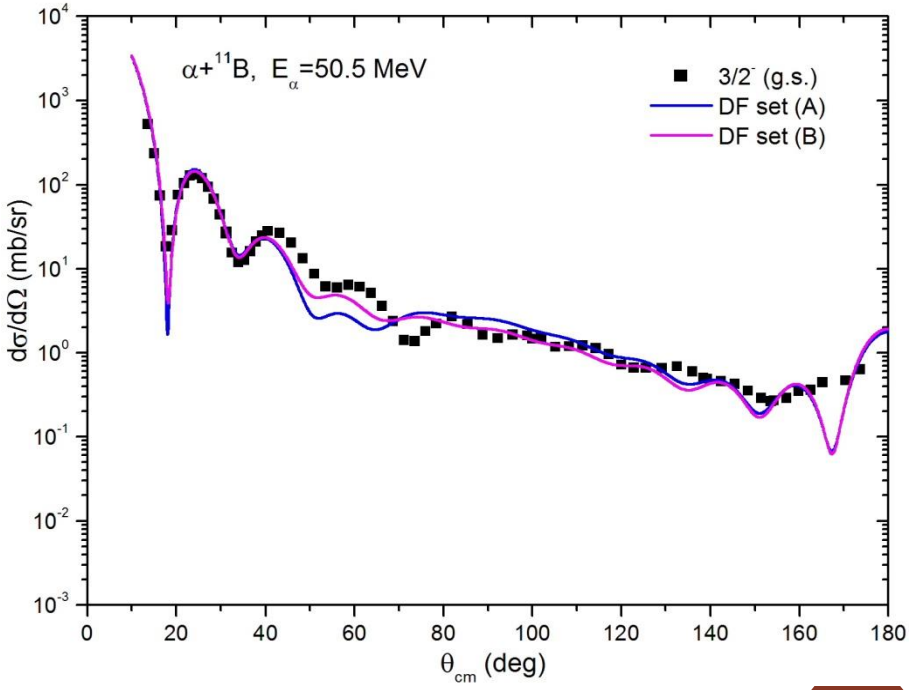
E MeV	Potential set	V_o MeV	r_v fm	a_v fm	W_o MeV	r_w fm	a_w fm	Nr
29	OM	79.55	1.2	0.743	23.65	1.76	0.438	
	DF				37.13	1.8	0.365	1.234
40	OM	77.85	1.245	0.856	19.01	1.57	0.7	
	DF				19.01	1.57	0.7	1.2
48.7	OM	76.0	1.245	0.825	15.89	1.57	0.801	
	DF				15.89	1.57	0.801	1.2
50	OM	77.22	1.245	0.856	16.85	1.57	0.833	
	DF				16.85	1.57	0.833	1.2
54.1	OM	80.73	1.245	0.822	15.08	1.57	0.85	
	DF				15.08	1.57	0.85	1.28

Results

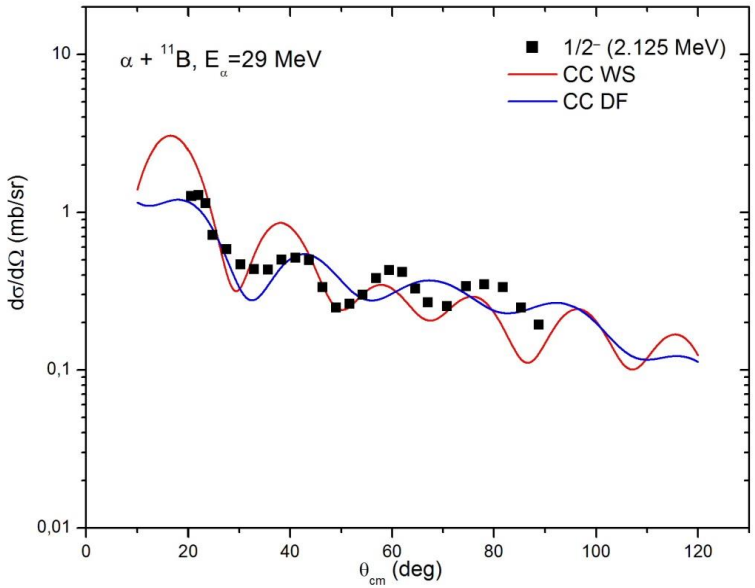




Elastic scattering of alpha particles from ^{11}B nuclei



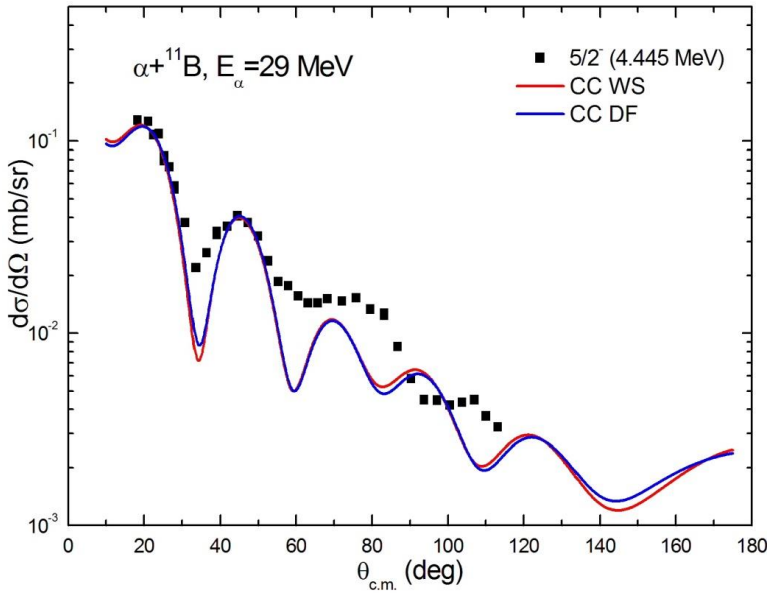
Excited states of ^{11}B

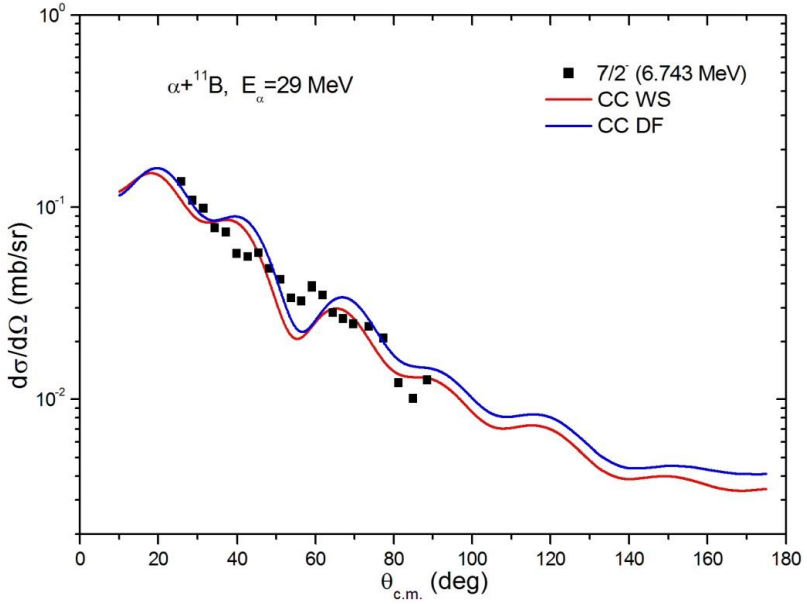


Excited states of ^{11}B nuclei: $1/2^-$, 2.125 MeV, $5/2^+$, 4.445 MeV $7/2^-$, 6.743 MeV at **E=29 MeV**, calculated within CC method.

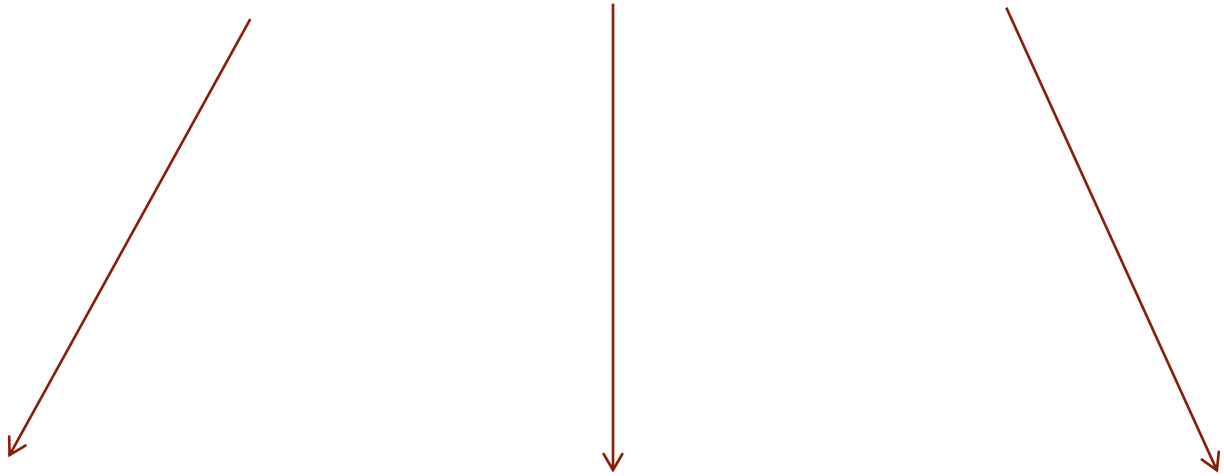
Deformation parameters:

E_{lab}, MeV	Potential	β (1/2-)	β (5/2-)	β (7/2-)	β (3/2-)
29 (E_α)	WS	0.45	0.46	0.44	0.41
	DF	0.45	0.46	0.44	
40.5 (E_α)	WS		0.42	0.42	0.42
	DF		0.4	0.42	
50.5 (E_α)	WS		0.35	0.4	
	DF		0.35	0.4	





The measurement of the radii of the excited state



Asymptotic Normalization Coefficients

Liu Z.H. et al.,PRC 64, 034312(2001)

Modified Diffraction Model

Danilov A.N. et. al. PRC 80, 054603 (2009)

Inelastic Nuclear Rainbow Scattering

Ohkubo S. PRC 70, 041602 (2004)

Modified Diffraction Model

The **modified diffraction model** assumes that the root-mean-square radius R_{rms}(ex.st) of the excited state can be determined through the difference of the diffraction radii of the excited and ground states:

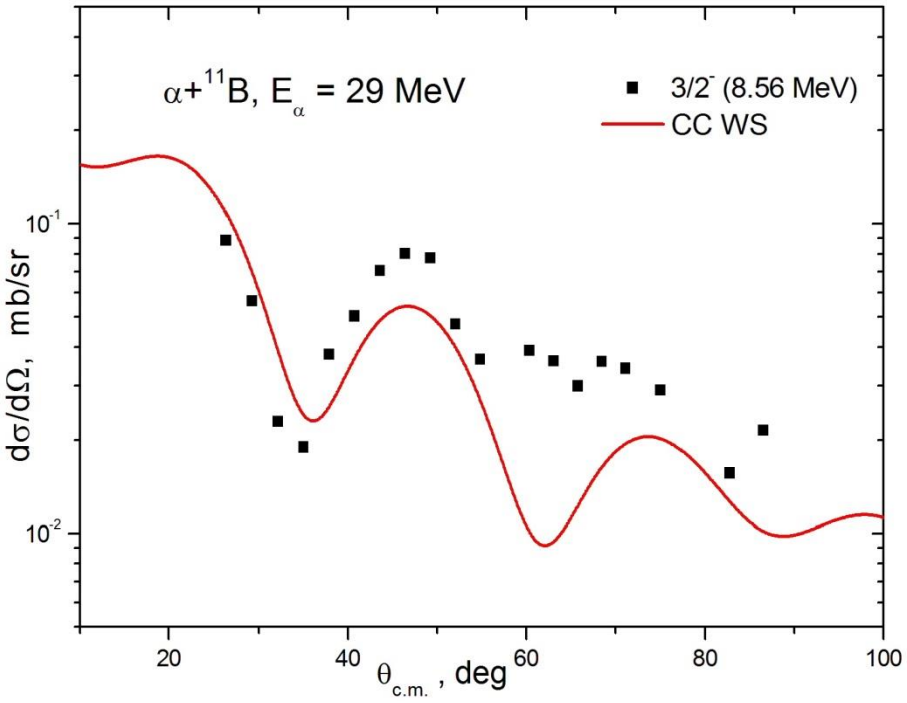
$$\mathbf{R_{rms}\ (ex.st.) = R_{rms}\ (g.s.) + [}\boldsymbol{R_{dif}(el) - R_{dif}\ (inel)]}$$

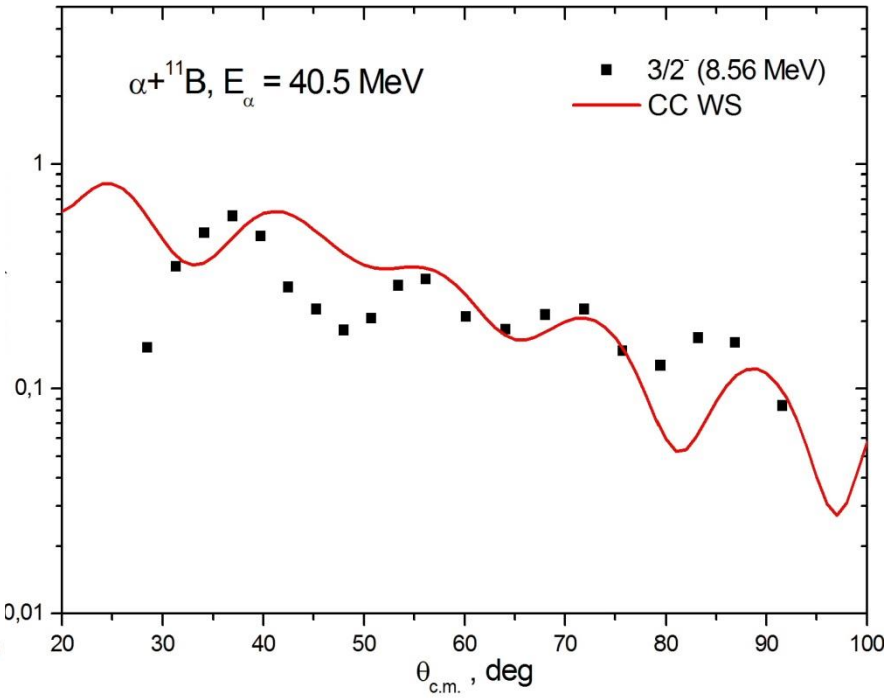
R_{dif}(el) and **R_{dif}(inel)** are the diffraction radii, are determined from the positions of the minima and maxima of the experimental angular distributions of the inelastic and elastic scattering, respectively.

Danilov A.N. et. al. PRC 80, 054603 (2009).

Analogues of Hoyle's state in ^{11}B

Observation of the exotic structure and the anomalously large radius of the Hoyle 0^+ (7.65 MeV) state in the ^{12}C nucleus prompted a number of assumptions that a similar situation may occur in neighboring ^{13}C and ^{11}B nuclei, which differ from ^{12}C, by adding a neutron or by removing the proton, respectively.





Analogues of Hoyle's state in ^{11}B

The rms radii of the excited state of the 8.56 MeV ($1/2^-$) **^{11}B** nucleus obtained in the framework of MDM in comparison with the 0^+ state of the ^{12}C nucleus

E^*, МэВ, I^π	R_{dif}, fm	R_{rms}, fm	E_α, MeV
7.65, 0^+ (^{12}C)	5.71±0.04	**2.89±0.04**	
8.56, $1/2^-$	5.64±0.09	**2.88±0.16**	29
8.56, $1/2^-$	5.66±0.10	**2.87±0.13**	65

E_{lab}, MeV	R_{rms} (g.s), fm	R_{rms} (2.12), fm	R_{rms} (4.445), fm	R_{rms} (5.02), fm	R_{rms} (6.74), fm
29	2.29	2.33±0.10	2.25 ±0.12		2.25 ± 0.15
40.5	2.29		2.17±0.08		2.22 ± 0.10
65		2.37 ±0.20	2.27±0.10	2.44±0.14	2.32 ± 0.14

Danilov A.N. et. al. PRC 80, 054603 (2009).

Conclusion

Indeed, the calculations made within the framework of **MDM, show** that the excited state of 8.56 MeV **has an increased** radius in **comparison with the ground state**. That is, it's similar to rms radius of Hoyle state.

We made conclusion, that the configuration of ^{11}**B** nucleus in this state will be regarded like as alpha + alpha + tritium or ^{7}Li + alpha.

Thank you for attention!