Наблюдение структуры в спектре рассеянных протонов под углом 21^0 в импульсной области, охватывающей квазиупругий *pN* – пик, в инклюзивной реакции (*p*, *p'*) с ядром ^{12}C при энергии 1 ГэВ

О. Миклухо

Аннотация:

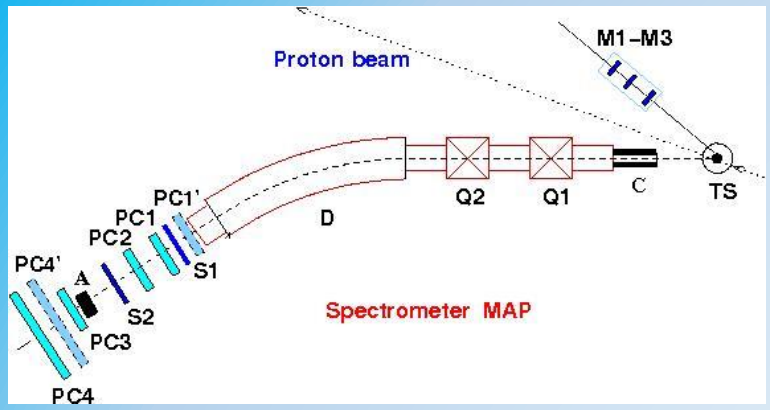
Наблюдаемая структура в импульсном распределении вторичных протонов возможно частично обусловлена дифракционным рассеянием протонов пучка на конституентах ядра углерода.

тема НИОКР 9.13. : "Исследование структуры ядерной материи на малых расстояниях в квазиупругих и неупругих протон-ядерных взаимодействиях при энергии 1 ГэВ

Experimental setup

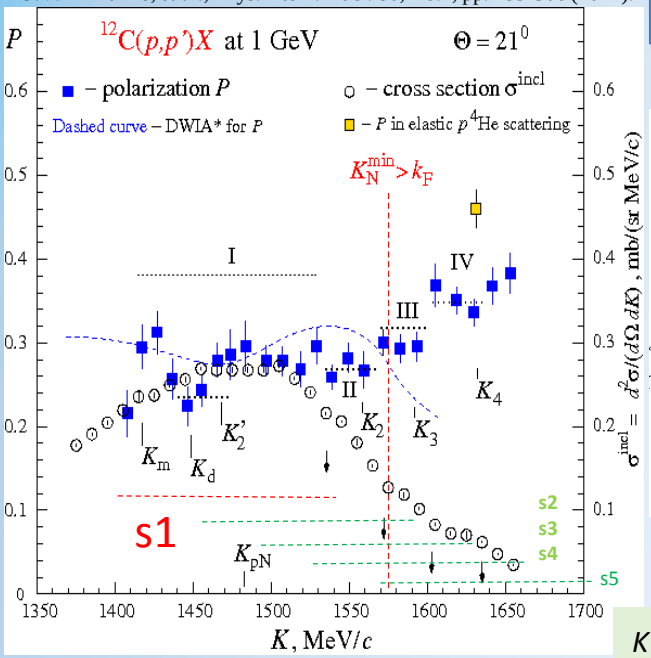
О. Миклухо

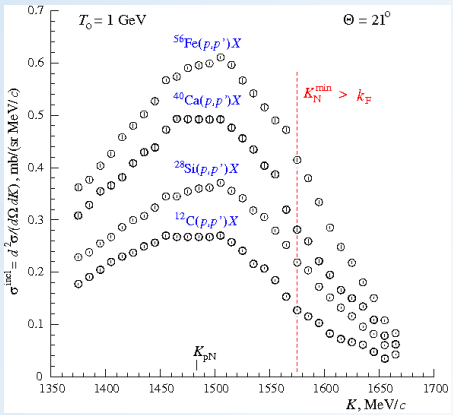
С.Л. Белостоцкий, Ю.В. Доценко, С.С. Волков, А.А. Воробьёв, Л.Г. Кудин, Н.П. Куропаткин, О.В. Миклухо, В.Н. Никулин, О.Е. Прокофьев, М.А. Шуваев. Препринт ЛИЯФ № 826, 1983, с.52.

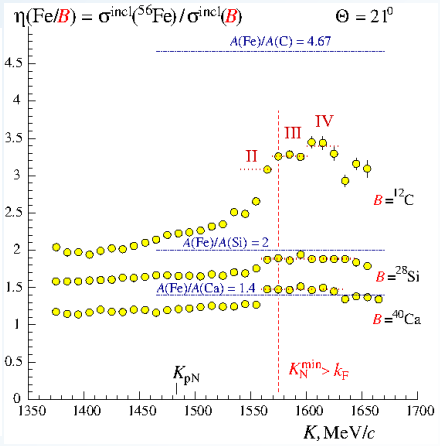


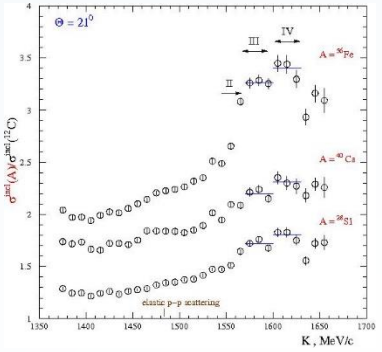
O.V. Miklukho, *et al.*, Phys. Atom. Nucl. **80**, No.2, pp. 299-306 (2017).

O.V. Miklukho, G.M. Amalsky, V.A. Andreev, O.Ya. Fedorov, K. Hatanaka, D. Ilyin, A.A. Izotov, A.Yu. Kisselev, M.P. Levchenko, T. Noro, A.N. Prokofiev, R. Revenko, H. Sakaguchi, A.V. Shvedchikov, A.Tatarenko, S.I. Trush, and A.A. Zhdanov, arXiv:1103.6113v1 [nucl ex] (2011). -> JETP Letters 102, 11 (2015).









O.V. Miklukho, *et al.*, JETP Letters, 2017, Vol. 106, No. 2, pp. 69–72, Pis'ma v ZhETF, 2017, vol. 106, iss. 2, pp. 63 – 64

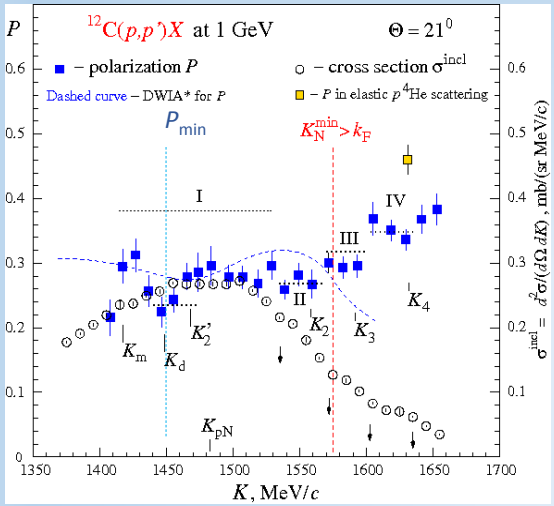
O.V. Miklukho, *et al.*, Phys. Atom. Nucl. **81**, No.3, pp. 320-329 (2018}.

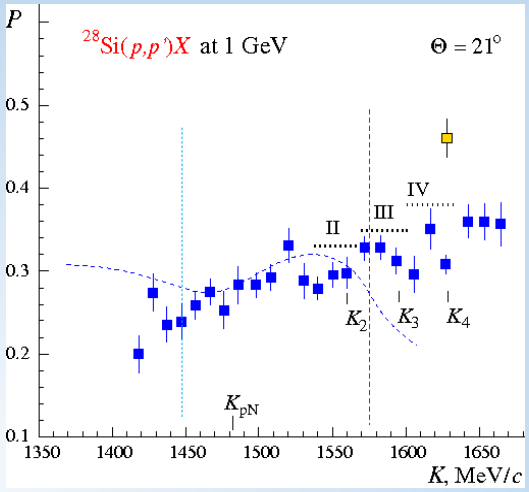
K = k1

s5: 1570-1710 MeV/*c*; s4: 1530-1670 MeV/*c*; s3: 1490-1630 MeV/*c*; s2: 1450-1590 MeV/*c*, s1: 1410-1540 MeV/*c*

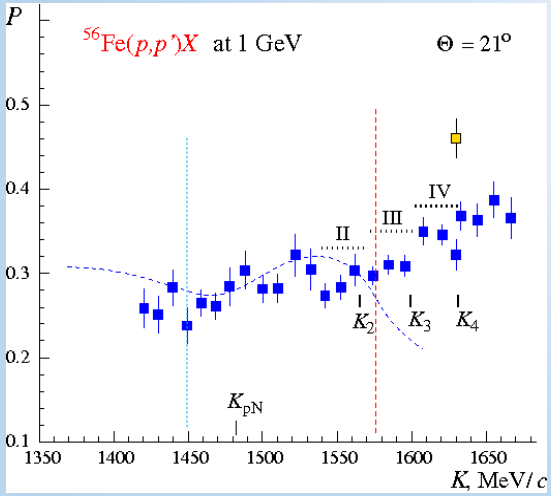
Polarization measurements at Θ = 21°

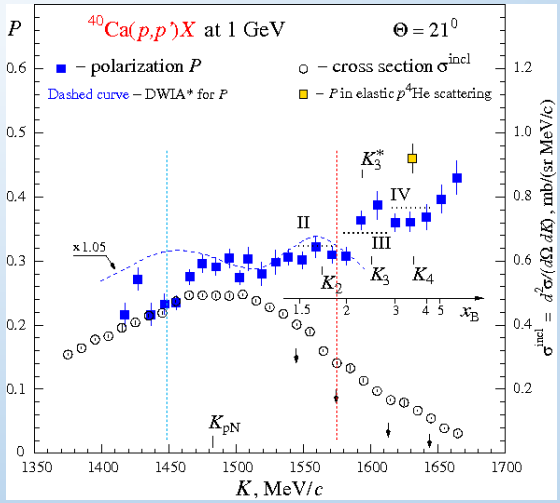
O.V. Miklukho *et al.*, PNPI Research Report "Main scientific activities 2013-2018" (HEPD), Gatchina, pp. 290-297 (2019),
arXiv:2102.04109v1 [nucl-ex] 8 Feb 2021,
PNPI Research Report "Main scientific activities 2018-2022" (HEPD), Gatchina, pp. 224-228 (2023).





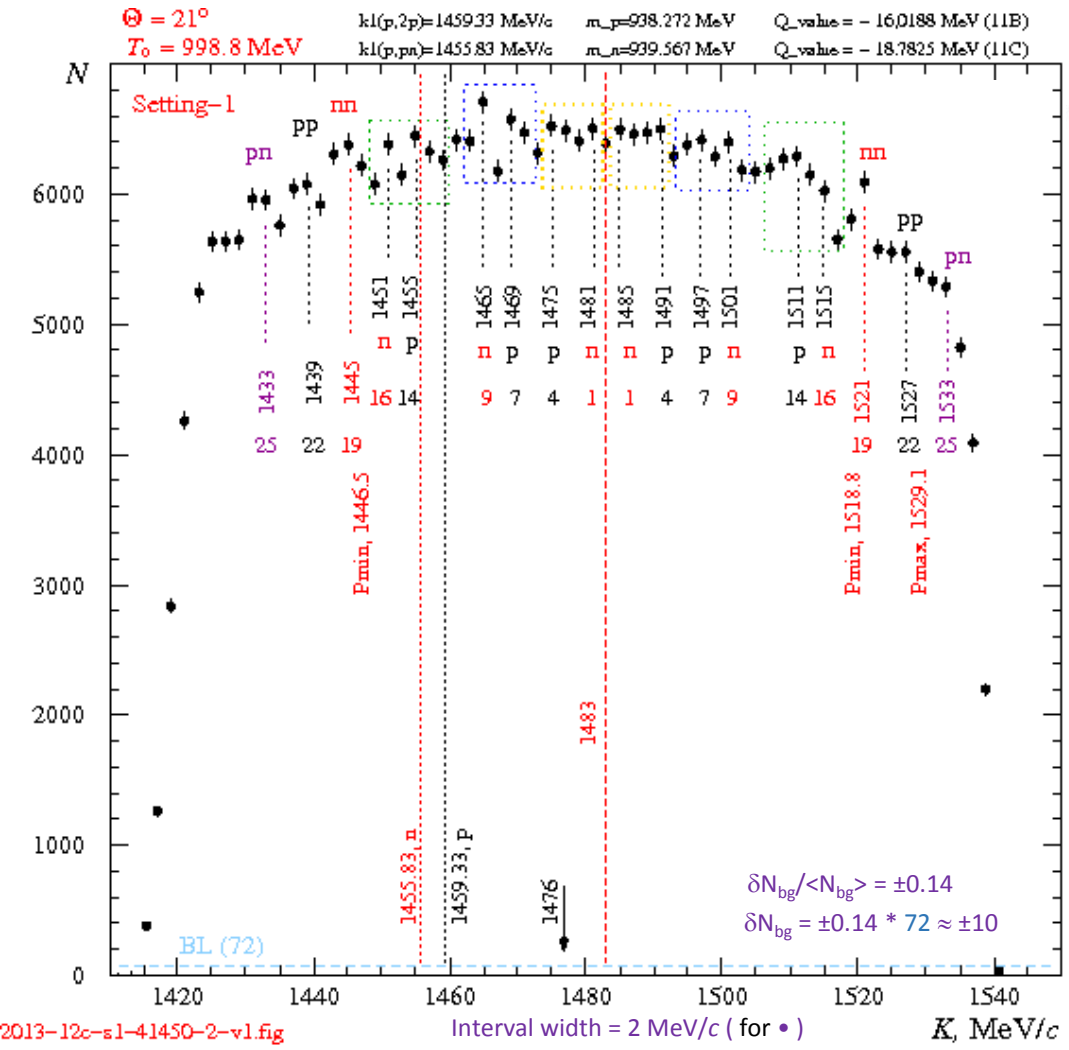
Сравнение :





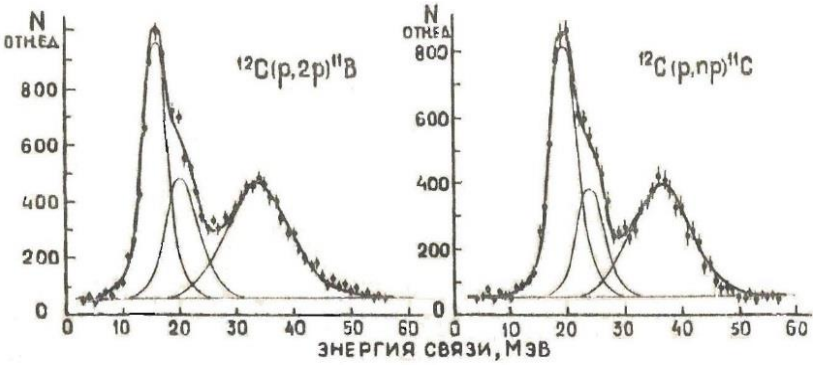
Minimum in polarization at $K \approx 1450$ MeV/c !!!

Momentum distribution (•) of secondary protons from the reaction $^{12}C(p, p')X$ at 1 GeV



В деформированном ядре углерода (^{12}C) протон и нейтрон находятся в трех одночастичных состояниях Ω^π с различной энергией связи e_p и e_n.

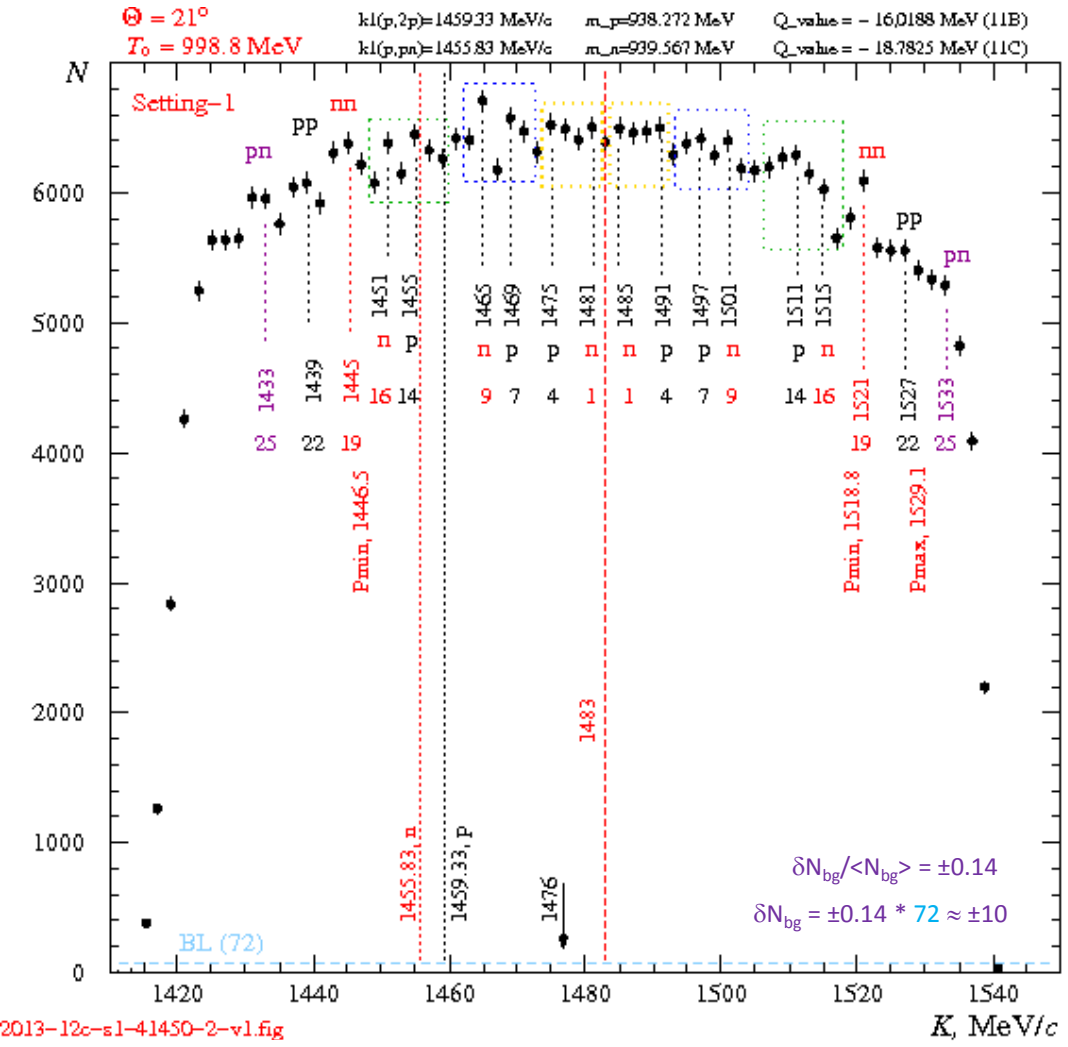
Ю.В. Доценко, В.Е.Стародубский «Деформационная структура легких ядер из реакции (p, 2p), (p, pn)», Препринт ЛИЯФ, № 970, Ленинград, июль 1984, 32 с.



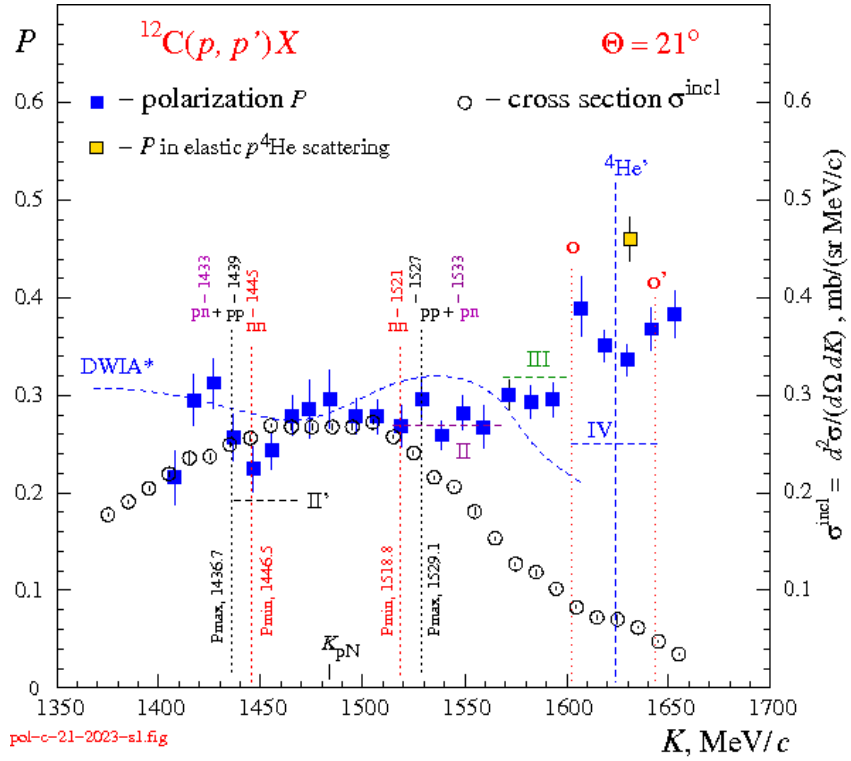
Энергии одночастичных состояний (МэВ)

	Ω^π	e_p экс.	e_p S7	e_p SII	e_p SIII	e_n экс.	e_n S7	e_n SII	e_n SIII
^{12}C	$1/2^-$	16.1(2)	16.4	16.3	16.6	19.0(2)	19.3	19.5	19.5
	$3/2^-$	20.4(4)	20.3	19.8	20.5	23.3(3)	23.3	23.1	23.5
	$1/2^+$	34.0(8)	35.9	36.9	31.9	36.3(6)	38.8	40.3	34.9
^{11}B	$3/2^-$	11.7(4)	11.8	12.3	13.3	11.5(5)	10.7	11.9	12.2
	$1/2^-$	17.5(4)	17.6	17.7	17.8	17.2(5)	17.4	17.7	17.5
	$1/2^+$	33.2(9)	34.7	35.9	34.7	33.9(8)	33.7	35.6	30.4
^{10}B	$3/2^-$	7.3(3)	7.5	8.3	9.7	9.2(4)	9.7	10.6	11.7
	$1/2^-$	17.5(3)	17.9	17.3	17.3	20.5(5)	20.4	21.1	20.9
	$1/2^+$	31.8(8)	31.4	32.7	28.7	32.2(8)	33.9	35.9	31.4
^{9}Be	$3/2^-$					2.0(2)	6.1	7.2	8.4
	$1/2^-$	17.1(3)	17.0	16.7	17.6	18.1(5)	18.2	18.6	18.6
	$1/2^+$	27.7(5)	31.1	32.6	29.4	29.2(8)	30.1	32.2	28.5
^{7}Li	$1/2^-$	10.3(3)	10.3	10.0	10.6	8.0(6)	8.0	8.1	8.2
	$1/2^+$	23.2(3)	25.5	27.6	25.5	26.0(6)	23.0	25.7	22.8
^{6}Li	$1/2^-$	4.9(2)	4.8	4.9	6.6	6.0(3)	6.1	6.6	8.0
	$1/2^+$	21.9(8)	20.6	22.9	21.1	23.7(4)	22.1	24.8	22.6

Cross section and polarization in the reaction $^{12}C(p, p')X$ at 1 GeV



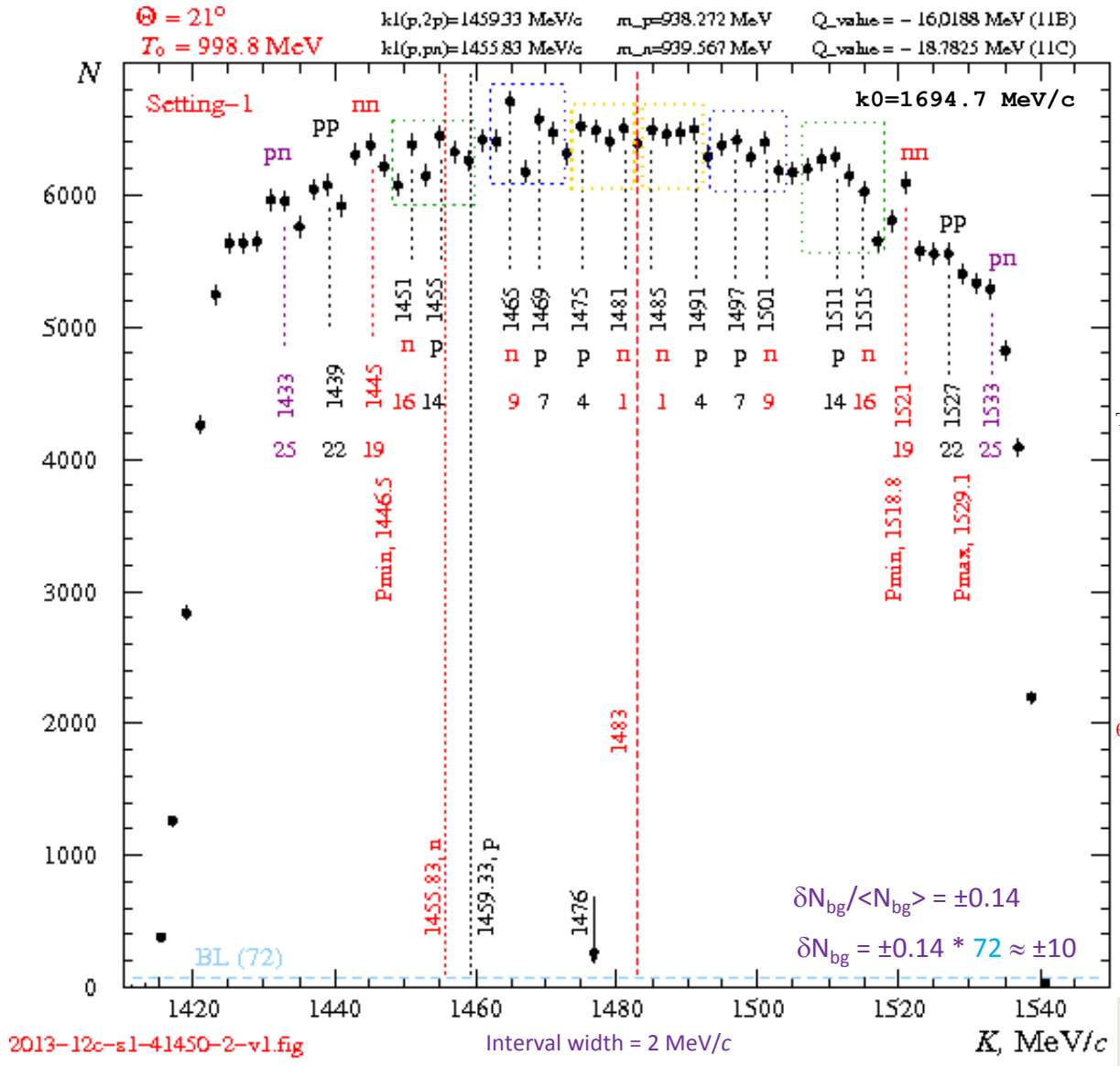
Interval width = 2 MeV/c (•)



Interval width = 10 MeV/c

$P_{pn\ elastics\ cattering} \sim 0.65\ P_{pp\ elastic\ scattering}$ at 1 GeV

Momentum distribution (•) of secondary protons from the reaction $^{12}C(p, p')X$ at 1 GeV



K=k1

$^{12}C(p, p'n)^{11}C$

m(^{12}C, free) =11174.866 MeV

m(^{11}C, free) =10254.084 MeV

m(n, free) = 939.565 MeV

Q_{value} (n) = -18.783 MeV

θmap = 21°, k1 = 1455.834 MeV/c, k2(0)=620.305 MeV/c, θ2(0)=57.254°, k3 = 0

Δm*(n) = +137.41 MeV Δm*(n)/m(n) = +14.6%

m*(n, mod) = **1076.977** MeV

Θmap = 21.000°, {Parallel Kinematics}-{ Θ2(0) = 59.732° and
k1 = 1483.00 MeV/c, T1 = 816.62 MeV, k2(0)=q(0)=615.348 MeV/c }
T2 = 163.4 MeV, k3 = 0.00025 MeV/c, Theta3 = +100.99° K3 = 0
m*(^{11}C) = 10116.672 MeV

$^{12}C(p, p'p)^{11}B$

m(^{12}C, free) =11174.866 MeV

m(^{11}B, free) =10252.613 MeV

m(p, free)=938.272 MeV

Q_{value} (p) = -16.019 MeV

θmap = 21°, k1 = 1459.327 MeV/c, k2(0)=619.601MeV/c, θ2(0)=57.571°, k3 = 0

Δm*(p) = +118.02 MeV Δm*(p)/m(p) = +12.6%

m*(p, mod) = **1056.288** MeV

Θmap = 21.000°, {Parallel Kinematics}- { Θ2(0) = 59.731°
k1 = 1482.99 MeV/c, T1=816. 61 MeV, k2(0)=q(0)= 615.349 MeV/c }
T2 = 166.17 MeV, k3 = 0.00020 MeV/c, Theta3 = +120.23° K3 = 0
m*(^{11}B) =10134.597 MeV

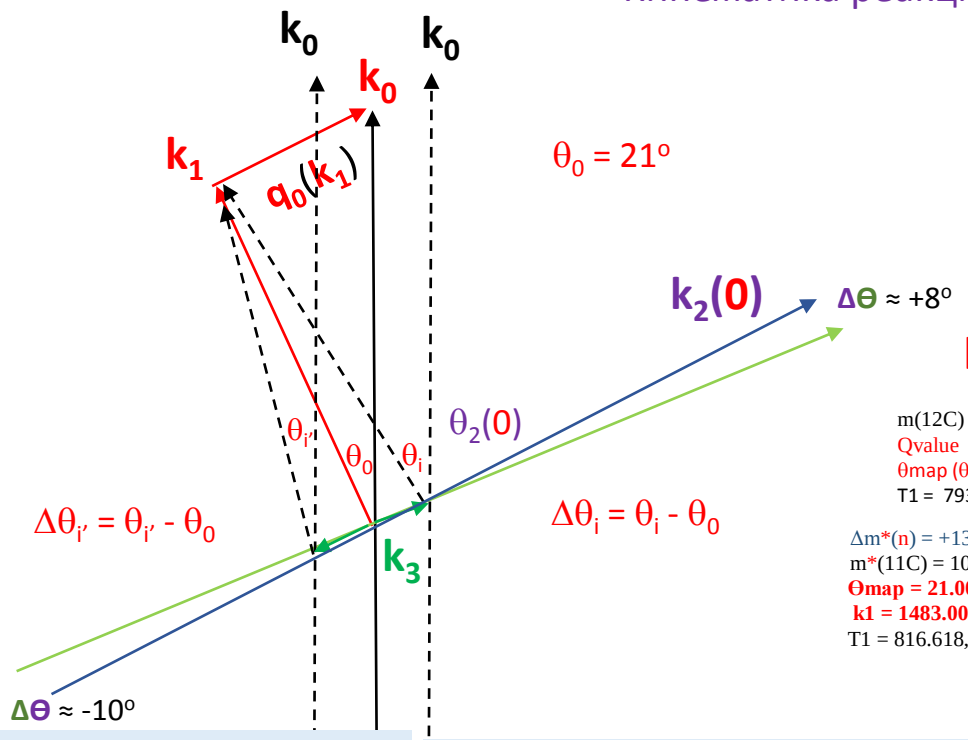
Parallel Kinematics:

Constituent (p, n) with momentum $\mathbf{k_2}$ is knocked out of the nucleus along the direction of the 3-momentum transfer $\mathbf{q = k_0 - k_1}$.

m(π^0) = 134.977 MeV m($\pi^{\pm}$) = 139.571 MeV

Кинематика реакции $^{12}C(p, p'n)^{11}C$

О. Миклухо



$T_0 + m_p + m(^{12}C) = T_1 + m_p + T_2 + m(n) + T_3 + m(^{11}C)$

$\omega = T_0 - T_1 = T_2 + T_3 + m(n) + m(^{11}C) - m(^{12}C)$

$\omega = T_0 - T_1 = T_2 + T_3 - Q_{value}$; Q_{value} = -18.78 MeV

$\omega = T_0 - T_1 = [(k_2^2 + m^*(n)^2)^{0.5} - m^*(n)] +$
$+ [k_3^2/2m^*(^{11}C)] - Q_{value}$;

$\mathbf{k_0 = k_1 + k_2 + k_3}$ $\mathbf{q(k_1) = k_0 - k_1}$ $\mathbf{q\,(k_1) - k_3 = k_2}$

m(12C) = 11174.866 MeV, m*(11C) = m(11C) = 10254.0835 MeV, !
Qvalue = -18.783 MeV, To = 998.8 MeV, k0 = 1694.666 MeV/c
θmap (θ_0) = 21°, k1 = 1455.834 MeV/c, { k2(0) = 620.305 MeV/c, θ2(0) = 57.254° }
T1 = 793.723 MeV, T2 = 186.295 MeV, k3 = 0 !

m*(n) = m(n) = 939.565 MeV

Δm*(n) = +137.411 MeV, Δm*(n)/m(n) = +14.625% !
m*(11C) = 10116.672 MeV

m*(n) = 1076.977 MeV

γ* = m*(n)/m(n) = 1.1463

Θmap = 21.000°, { Θ2 (0) = 59.732° } < {Parallel Kinematics}
k1 = 1483.000 MeV/c, { k2(0) = q_0 = 615.348 MeV/c ! }
T1 = 816.618, T2(0) = 163.399, k3 = 0.00025 !, Theta3 = +100.990°

$k_3 = 0$

$\omega = T_0 - T_1 = [(k_2^2 + m^*(n)^2)^{0.5} - m^*(n)] - Q_{value}$

$\mathbf{q_0(k_1) = k_2(0)}$

θ_i = Θmap = 22.878°, Θ2 = 57.613°
k1 = 1451.0000 MeV/c !, K2 = 668.022
T1 = 789.662, T2 = 190.356, k3 = 0 !
$\Delta\theta_i$ = +1.878°, $|\Delta\theta_i| > |\Delta\Theta_g| \approx 0.4°$

K3-study : k1 = 1482.861 MeV/c, Θ_i = 22.878°, { k2(0) = 615.348 MeV/c, Θ2(0) = 59.732° }
T1 = 816.502, T2(0) = 163.399, k3 = 48.612 MeV/c , Theta3 = -67.8988°, Θ_i - Theta3= 90.776°
β = k2(0)/E2*(0) = 0.497. ΔΘ = ITheta3I - Θ2(0) = +8.17°, T_n (k3) = k3^2 / 2m*(n) = 1.16 MeV

$\theta_{i'}$ = Θmap = 19.002°, Θ2 = 62.006°
k1 = 1515.000 MeV/c !, K2 = 558.658
T1 = 843.743, T2 = 136.274, k3 = 0 !
$\Delta\theta_{i'}$ = -1.998°, $|\Delta\Theta_{i'}| > |\Delta\Theta_g| \approx 0.4°$

K3-study : k1 = 1482.843 MeV/c, $\Theta_{i'}$ = 19.002°, { k2(0) = 615.348 MeV/c, Θ2(0) = 59.732° }
T1= 816.486, T2(0)= 163.399, k3 = 51.704 MeV/c , Theta3 = +109.828°, Theta3 – $\Theta_{i'}$ = 90.826°
β = k2(0)/E2*(0) = 0.497, γ = 1.1524, ΔΘ = ITheta3I – (180° - Θ2(0)) = - 10.44°

[K = k1, k2(0), k2, q_0 , k3] – MeV/c

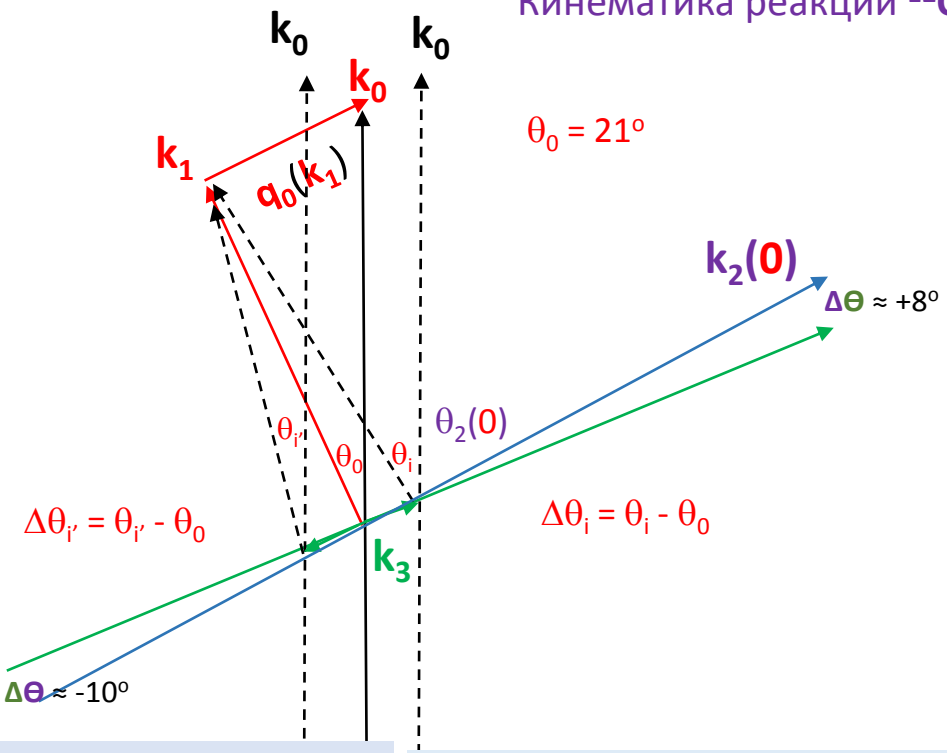
[T1, T2(0), E2*(0), T2] – MeV

Импульс k_1, равный 1483 МэВ/*c*, отвечает оси симметрии в импульсном распределении (ИР) при угле рассеяния протонов θ_0 = 21° и модифицированной массе нейтрона m*(n) 1076.98 МэВ (+14.625%). Масса свободного нейтрона m(n) - 939.565 МэВ, масса ядра остатка (^{11}C) = 10254.08 МэВ. Δm*(n) = m*(n) - m(n) = +137.412 МэВ. Масса π^o – мезона = 134.98 МэВ, масса $\pi^+(\pi^-)$ – мезона = 139.571 МэВ.

$\Delta\Theta_g \approx \pm 0.4°$ – геометрический горизонтальный угловой захват МАПа

О. Миклухо

Кинематика реакции $^{12}C(p, p'p)^{11}B$



$T_0 + m_p + m(^{12}C) = T_1 + m_p + T_2 + m(p) + T_3 + m(^{11}B)$

$\omega = T_0 - T_1 = T_2 + T_3 + m(p) + m(^{11}B) - m(^{12}C)$

$\omega = T_0 - T_1 = T_2 + T_3 - Q_{value}$; $Q_{value} = -16.018$ MeV

$\omega = T_0 - T_1 = [(k_2^2 + m^*(p)^2)^{0.5} - m^*(p)] + [k_3^2/2m^*(^{11}B)] - Q_{value}$;

$k_0 = k_1 + k_2 + k_3$ $q(k_1) = k_0 - k_1$ $q(k_1) - k_3 = k_2$

m(12C) = 11174.866 MeV, m*(11B) = m(11B) = 10252.613 MeV, m*(p) = m(p) = **938.272** MeV
Qvalue = -16.018 MeV, To = 998.8 MeV, k0 = 1694.666 MeV/c,
θmap (θ_0) = **21°**, **k1 = 1459.327 MeV/c**, {k2(0) = 619.601 MeV/c, θ2(0) = 57.571° }
T1 = 796.660 MeV, T2 = 186.121 MeV, **k3 = 0**

Δm*(p) = +118..016 MeV, Δm*(p)/m(p) = +12.578% ! m*(p) = **1056.288** MeV γ* = m*(p)/m(p) = 1.1258
m*(11B) = 10134.597 MeV,
Θmap = 21.000°, { Θ2(0) = 59.731° }
k1 = 1482.993 MeV/c, { k2(0) = q_0 = 615.349 MeV/c }
T1=816.613, T2(0)=166.168, **k3 = 0.0002** MeV/c , **Theta3 = 120.228°**

< {Parallel Kinematics}

$k_3 = 0$

$\omega = T_0 - T_1 = [(k_2^2 + m^*(p)^2)^{0.5} - m^*(p)] - Q_{value}$;

$q_0(k_1) = k_2(0)$

θ_i = Θmap = **22.623°**, Θ2 = 57.861°
k1 = 1455.000 MeV/c !, k2 = 660.976
T1 = 793.022, T2 = 189.759, **k3 = 0 !**
$\Delta\theta_i$ = +1.623° , $|\Delta\theta_i| > |\Delta\Theta_g| \approx 0.4°$

K3-study: k1 = 1482.890 MeV/*c*, Θ_i **= 22.623°, { k2(0) = 615.349** MeV/*c*, **Θ2(0) = 59.731° }**
T1 = 816.526, T2(0) = 166.168, **k3 = 42.006** MeV/c; **Theta3 = -68.048°, Θ_i - Theta3 = 90.671°**
β = **k2(0)/E2*(0) = 0.503,** γ = 1.157, **ΔΘ** = ITheta3I - **Θ2(0)** = +8.32°

$\theta_{i'}$ = Θmap = **19.288°**, Θ2 = 61.724°
k1 = 1511.000 MeV/c !, k2 = 566.743
T1 = 840.344, T2 = 142.437, **k3 = 0 !**
$\Delta\theta_{i'}$ = -1.712°, $|\Delta\Theta_{i'}| > |\Delta\Theta_g| \approx 0.4°$

K3-study: k1 = 1482.878 MeV/*c*, $\Theta_{i'}$ **= 19.288°, { k2(0) = 615.349** MeV/*c*, **Θ2(0) = 59.731° }**
T1 = 816.516, T2(0) = 166.168, **k3 = 44.302** MeV/c, **Theta3 = +109.996, Theta3 – $\Theta_{i'}$ = 90.708°**
β = **k2(0)/E2*(0) = 0.503,** γ = 1.157, **ΔΘ** = ITheta3I – (180° - **Θ2(0)**) = -10.27°

[*K* = k1, **k2(0)**, k2, **q_0** , **k3**] – MeV/*c*

[T1, T2(0),), **E2*(0)**, ,T2] – MeV

Импульс k_1, равный 1483 МэВ/*c*, отвечает оси симметрии в импульсном распределении (ИР) при угле рассеяния протонов $\theta_0 = 21°$ и модифицированной массе ядерного протона m*(p) 1056.29 МэВ (+12.578%). Масса свободного протона m(p) - 938.272 МэВ, масса ядра остатка (^{11}B) = 10252.6128 МэВ. Δ*m(p) = m*(p) - m(p) = +118.01 МэВ. Масса π^o – мезона = 134.98 МэВ, масса $\pi^+(\pi^-)$ – мезона = 139.571 МэВ.

$\Delta\Theta_g \approx \pm 0.4°$ – геометрический горизонтальный угловой захват МАПа

1 Результаты вычислений для реакций $^{12}C(p, p'n)^{11}C$ и $^{12}C(p, p'p)^{11}B$

$^{12}C(p, p'n)^{11}C$

m(n)= **939.565 MeV**
Qvalue = -18.783 MeV

m*(n) = **1076.977 MeV**
Δm*(n) = +137.411 MeV, Δm*(n)/m(n) = +14.625%

Θmap = 21.000°, {**Θ2(0) = 59.732°** }
k1 = 1483.000, {**k2(0) = q_0 = 615.348**}
T1 = 816.618, T2 = 163.399,
k3 = 0.00025, Theta3 = +100.990°

Θmap = 22.878°, Θ2 = 57.613°
k1 = 1451.000, K2 = 668.022
T1 = 789.662, T2 = 190.356, **k3 = 0**

K3-study : k1 = 1482.861, {Θmap = 22.878°, k2(0) = 615.348, !!! Θ2(0) = 59.732°}
T1 = 816.502, T2 = 163.399, **k3 = 48.612, Theta3 = -67.899°, Θmap - Theta3= 90.776°**
ΔΘmap = +1.878°

Θmap = **19.002°**, Θ2 = 62.006°
k1 = 1515.000, K2 = 558.658
T1= 843.743, T2 = 136.274, **k3 = 0**

K3-study : k1 = 1482.843, {Θmap = 19.002°, k2(0) = 615.348, !!! Θ2(0) = 59.732°}
T1 = 816.486, T2 = 163.399, **k3 = 51.704, Theta3 = +109.828°, Theta3 – Θmap = 90.826°**
ΔΘmap = -1.998°

[*K*=**k1**, **k2(0)**, q_0, **k3**] – MeV/*c*

[T1, T2] – MeV

$^{12}C(p, p'p)^{11}B$

m(p)= **938.272 MeV**
Qvalue = -16.018 MeV

m*(p) = **1056.288 MeV**
Δm*(p)= +118.016 MeV, Δm*(p)/m(p) = +12.578%

Θmap = 21.000°, { **Θ2(0) = 59.731°** }
k1 = 1482.993, { **k2(0) = q_0 = 615.349** }
T1 = 816.613, T2 = 166.168
k3 = 0.0002, Theta3 = +120.228°

Θmap = 22.623°, Θ2 = 57.861°
k1 = 1455.000, k2 = 660.976
T1 = 793.022, T2 = 189.759, **k3 = 0**

K3-study: k1 = 1482.890, {Θmap = 22.623°, k2(0) = 615.349, !!! Θ2(0) = 59.731°}
T1 = 816.526, T2 = 166.168, **k3 = 42.006, Theta3 = -68.048°, Θmap - Theta3 = 90.671°**
ΔΘmap = +1.623°

Θmap = 19.288°, Θ2 = 61.724°
k1 = 1511.000, k2 = 566.743
T1 = 840.344, T2 = 142.437, **k3 = 0**

K3-study: k1 = 1482.878, {Θmap = 19.288°, k2(0) = 615.349, !!! Θ2(0) = 59.731°}
T1 = 816.516, T2 = 166.168, **k3 = 44.302°, Theta3 = +109.996°, Theta3 – Θmap = 90.708°**
ΔΘmap = -1.712°

Observation : k1 has the same value, ≈1483 MeV/*c*,
in the **Parallel Kinematics :**
k2(0) = 615.35 MeV/c, and Θ2(0) = 59.73°

2 Результаты вычислений для реакций $^{12}C(p, p'n)^{11}C$ и $^{12}C(p, p'p)^{11}B$

$^{12}C(p, p'n)^{11}C$

m(n)= **939.565 MeV**
Qvalue = -18.783 MeV

m*(n) = **1076.977 MeV**
Δm*(n) = +137.411 MeV, Δm*(n)/m(n) = +14.625%

θ_i = Θmap = **22.069°**, Θ2 = 58.523°
k1 = 1465.0000 MeV/*c* !, K2 = 645.408
T1 = 801.435, T2 = 178.583, **k3 = 0 !**
$\Delta\theta_i$ = +1.069°, $|\Delta\theta_i| > |\Delta\Theta_g| \approx 0.4°$

K3-study : **k1 = 1482.954** MeV/*c*, **Θ_i = 22.069°, { k2(0) = 615.348** MeV/c, **Θ2(0) = 59.732° }**
T1 = 816.581, T2(0) = 163.399, **k3 = 27.67** MeV/*c* , **Theta3 = -68.373°, Θ_i - Theta3= 90.441°**

$\theta_{i'}$ = Θmap = **19.893°**, Θ2 = 60.989°
k1 = 1501.000 MeV/c !, K2 = 584.024
T1 = 831.856, T2 = 148.161, **k3 = 0 !**
$\Delta\theta_{i'}$ = -1.107°, $|\Delta\Theta_{i'}| > |\Delta\Theta_g| \approx 0.4°$

K3-study : **k1 = 1482.951** MeV/c, **$\Theta_{i'}$ = 19.893°, { k2(0) = 615.348** MeV/*c*, **Θ2(0) = 59.732° }**
T1= 816.578, T2(0)= 163.399, **k3 = 28.643** MeV/*c* , **Theta3 = +110.351°, Theta3 – $\Theta_{i'}$ = 90.457°**

$^{12}C(p, p'p)^{11}B$

m(p)= **938.272 MeV**
Qvalue = -16.018 MeV

m*(p) = **1056.288 MeV**
Δm*(p)= +118.016 MeV, Δm*(p)/m(p) = +12.578%

θ_i = Θmap = **21.821°**, Θ2 = 58.783°
k1 = 1469.000 MeV/c **!**, k2 = 638.487
T1 =804.804, T2 = 177.977, **k3 = 0 !**
$\Delta\theta_i$ = +0.821° , $|\Delta\theta_i| > |\Delta\Theta_g| \approx 0.4°$

K3-study: k1 = 1482.890 MeV/*c*, **Θ_i = 21.821°, { k2(0) = 615.349** MeV/*c*, **Θ2(0) = 59.731° }**
T1 = 816.591, T2(0) = 166.168, **k3 = 21.248** MeV/c; **Theta3 = -68.519°, Θ_i - Theta3 = 90.34°**

$\theta_{i'}$ = Θmap = **20.156°**, Θ2 = 60.711°
k1 = 1497.000 MeV/c **!**, k2 = 591.452
T1 = 828.466, T2 = 154.315, **k3 = 0 !**
$\Delta\theta_{i'}$ = -0.844°, $|\Delta\Theta_{i'}| > |\Delta\Theta_g| \approx 0.4°$

K3-study: k1 = 1482.965 MeV/*c*, **$\Theta_{i'}$ = 20.156°, { k2(0) = 615.349** MeV/*c*, **Θ2(0) = 59.731° }**
T1 = 816.590, T2(0) = 166.168, **k3 = 21.835** MeV/c, **Theta3 = +110.505, Theta3 – $\Theta_{i'}$ = 90.35°**

[*K*=**k1**, **k2**, **k3**] – MeV/*c*

[T1, T2, T2(0)] – MeV

Анализ результатов вычислений

Observations:

$^{12}C(p, p'n)^{11}C$

$m^*(n) = 1076.977$ MeV $m(n) = 939.565$ MeV $m(\pi^o) = 134.977$ MeV

$Q_{value}\ (k=0) = m^*(n) - \{m(n) + m(\pi^o)\} = +\ 2.435$ MeV > 0

$m^*(n) = 1076.977$ MeV $m(p) = 938.272$ MeV $m(\pi^-) = 139.571$ MeV

$Q_{value}\ (k=0) = m^*(n) - \{m(p) + m(\pi^-)\} = -\ 0.866$ MeV < 0

$m^*(n) = \mathbf{1076.977\ MeV}$

$\Delta m^*(n) = +137.411$ MeV,

$\Delta m^*(n)/m(n) = +14.625\%$

$Q_{value} = -18.783$ MeV

$^{12}C(p, p'p)^{11}B$

$m^*(p) = 1056.288$ MeV $m(p) = 938.272$ MeV $m(\pi^o) = 134.977$ MeV

$Q_{value}\ (k=0) = m^*(p) - \{m(p) + m(\pi^o)\} = -\ 16.961$ MeV < 0

$m^*(p) = 1056.288$ MeV $m(n) = 939.565$ MeV $m(\pi^+) = 139.571$ MeV

$Q_{value}\ (k=0) = m^*(p) - \{m(n) + m(\pi^+)\} = -\ 22.848$ MeV < 0

$m^*(p) = \mathbf{1056.288\ MeV}$

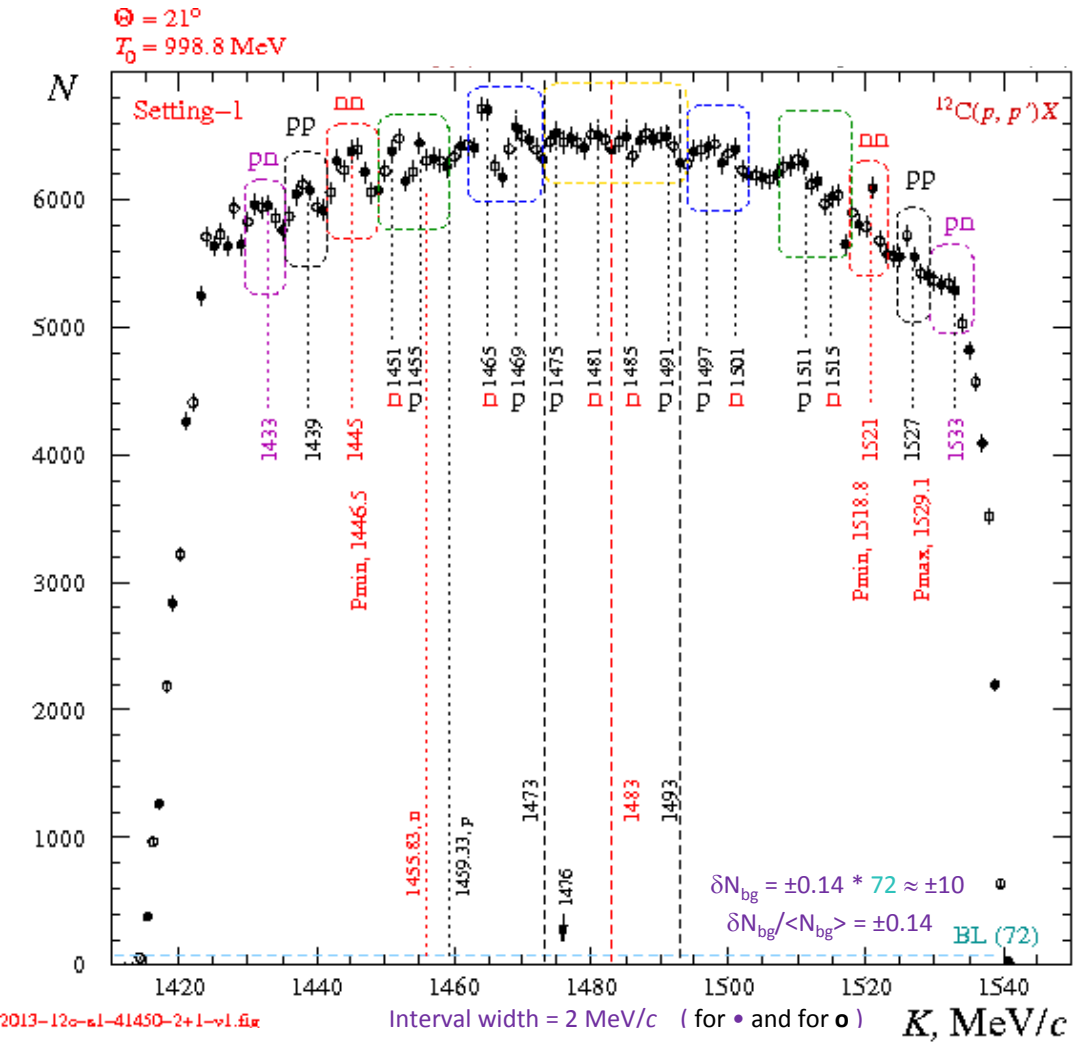
$\Delta m^*(p) = +118.016$ MeV,

$\Delta m^*(p)/m(p) = +12.578\%$

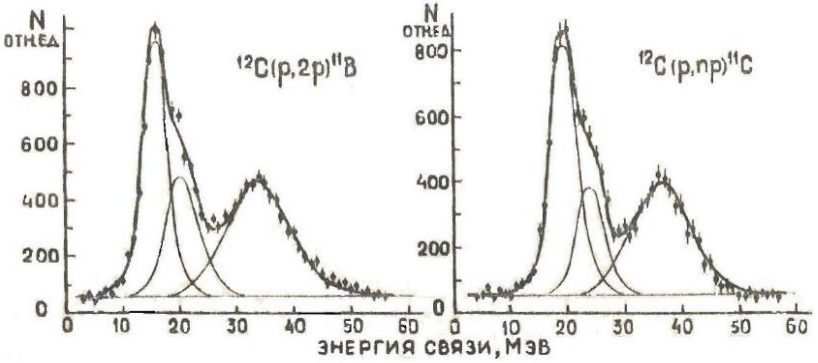
$Q_{value} = -16.018$ MeV

Анализ структуры вне области преимущественного рассеяния на ядерных нуклонах

Momentum distributions (• *and* ○) of secondary protons from the reaction $^{12}C(p, p')X$ at 1 GeV



Ю.В. Доценко, В.Е.Стародубский «Деформационная структура легких ядер из реакции (p, 2p), (p, pn)», Препринт ЛИЯФ, № 970, Ленинград, июль 1984, 32 с.



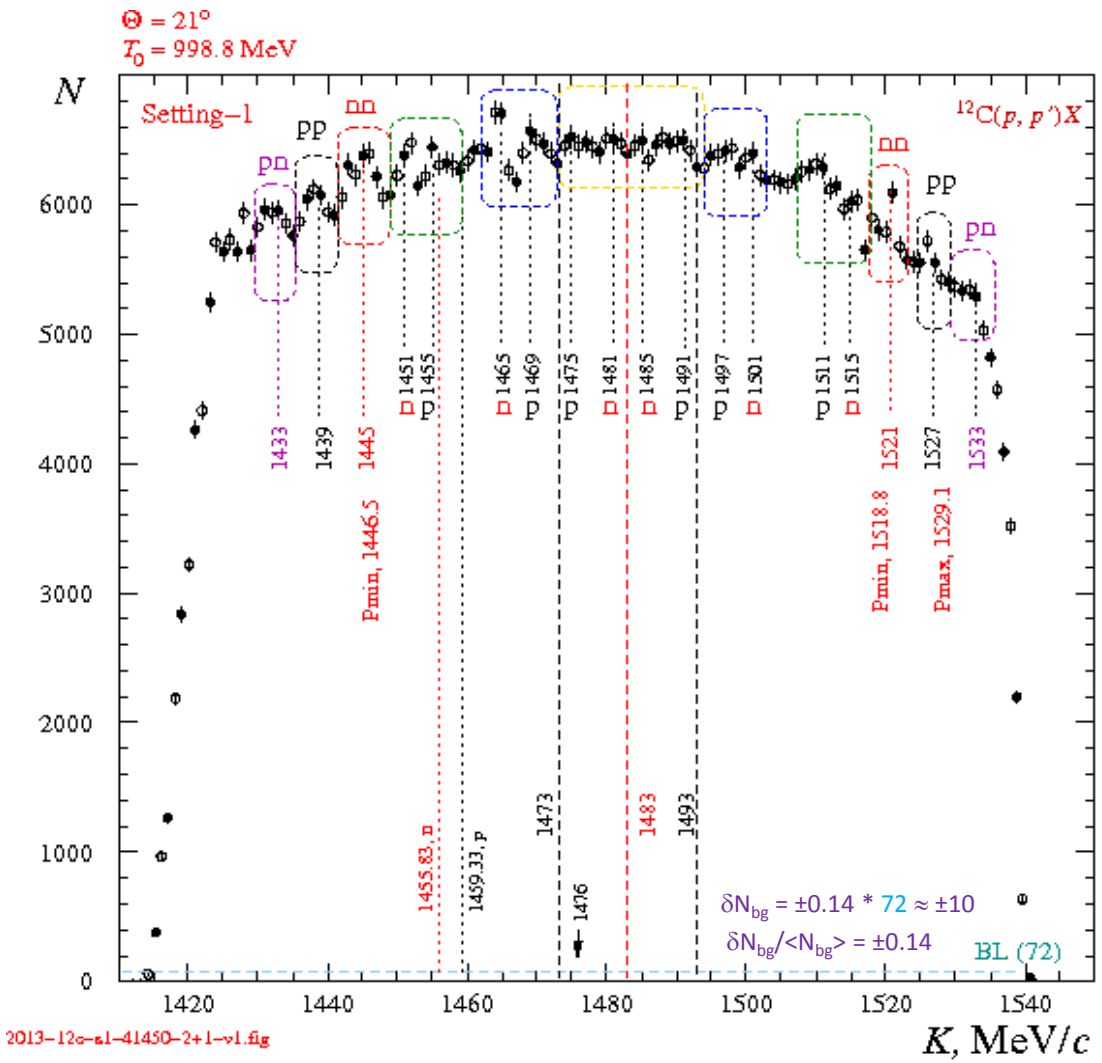
Энергии одночастичных состояний (МэВ)

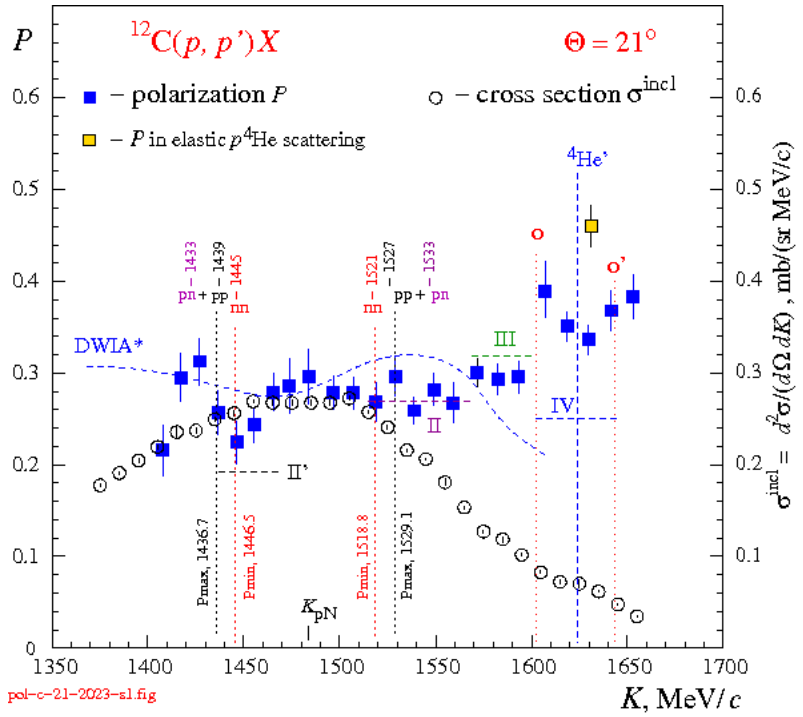
		e_p				e_n			
	Ω^π	эксп.	S7	SII	SIII	эксп.	S7	SII	SIII
^{12}C	1/2⁻	16.1(2)	16.4	16.3	16.6	19.0(2)	19.3	19.5	19.5
	3/2⁻	20.4(4)	20.3	19.8	20.5	23.3(3)	23.3	23.1	23.5
	1/2⁺	34.0(8)	35.9	36.9	31.9	36.3(6)	38.8	40.3	34.9
^{11}B	3/2⁻	11.7(4)	11.8	12.3	13.3	11.5(5)	10.7	11.9	12.2
	1/2⁻	17.5(4)	17.6	17.7	17.8	17.2(5)	17.4	17.7	17.5
	1/2⁺	33.2(9)	34.7	35.9	34.7	33.9(8)	33.7	35.6	30.4
^{10}B	3/2⁻	7.3(3)	7.5	8.3	9.7	9.2(4)	9.7	10.6	11.7
	1/2⁻	17.5(3)	17.9	17.3	17.3	20.5(5)	20.4	21.1	20.9
	1/2⁺	31.8(8)	31.4	32.7	28.7	32.2(8)	33.9	35.9	31.4
^{9}Be	3/2⁻					2.0(2)	6.1	7.2	8.4
	1/2⁻	17.1(3)	17.0	16.7	17.6	18.1(5)	18.2	18.6	18.6
	1/2⁺	27.7(5)	31.1	32.6	29.4	29.2(8)	30.1	32.2	28.5
^{7}Li	1/2⁻	10.3(3)	10.3	10.0	10.6	8.0(6)	8.0	8.1	8.2
	1/2⁺	23.2(3)	25.5	27.6	25.5	26.0(6)	23.0	25.7	22.8
^{6}Li	1/2⁻	4.9(2)	4.8	4.9	6.6	6.0(3)	6.1	6.6	8.0
	1/2⁺	21.9(8)	20.6	22.9	21.1	23.7(4)	22.1	24.8	22.6

В деформированном ядре углерода (^{12}C) протон и нейтрон находятся в трех одночастичных состояниях Ω^π с различной энергией связи e_p и e_n.

Cross sections and polarization in the reaction $^{12}C(p, p')X$ at 1 GeV

О. Миклухо





Interval width = 10 MeV/*c*

Interval width = 2 MeV/*c* (for • *and* for o)

$P_{p4He\text{-}elastic\ scatering}$ (≈ 0.45) > $P_{<pp\text{-}pn>}$ (≈ 0.35} at 21°

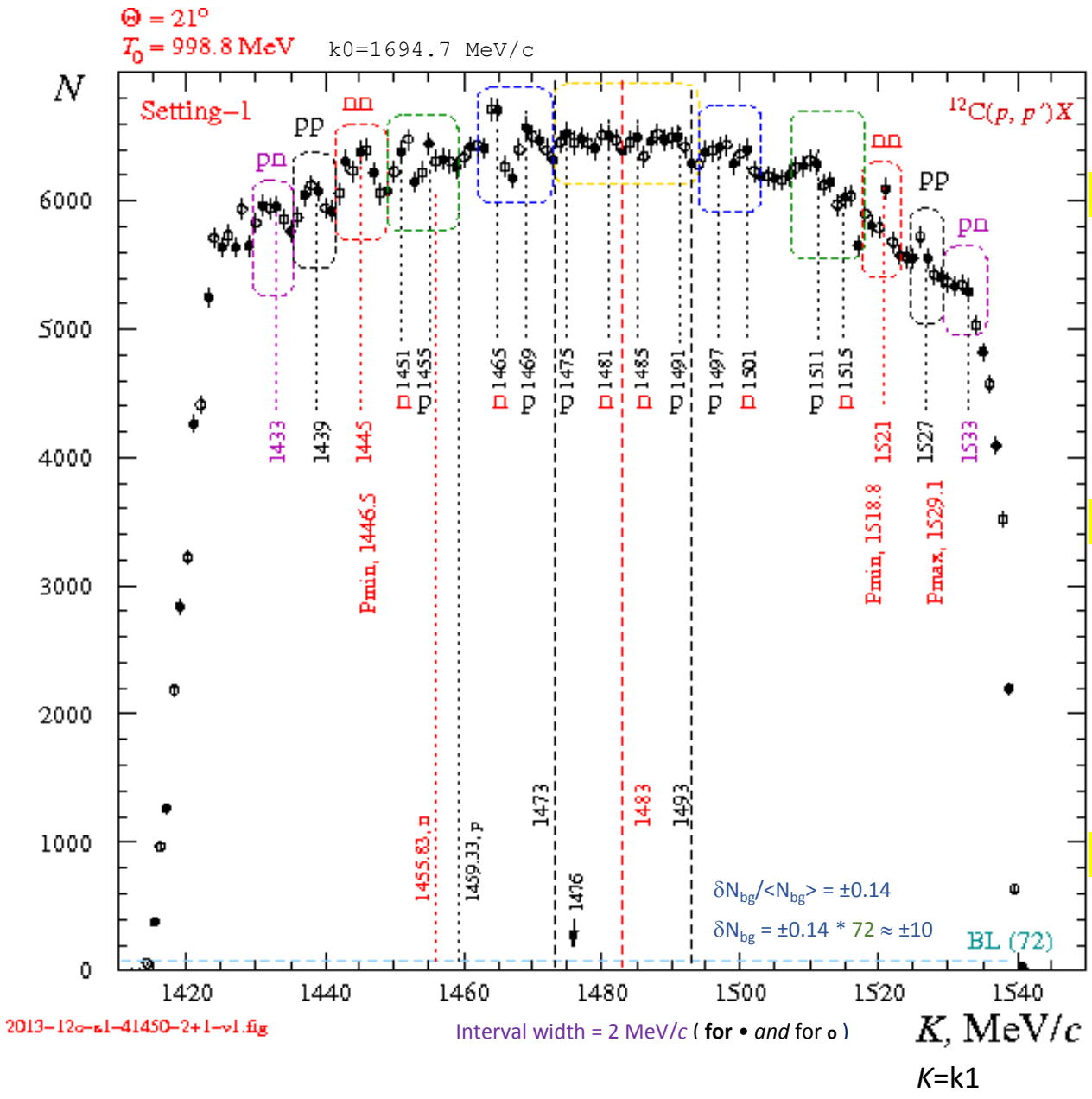
O.V. Miklukho et al., Phys. At. Nucl. 69, 474 (2006).

Короткодействующие нуклонные корреляции в ядрах (SRC) :
L. Frankfurt, M. Sargsian, M. Strikman, arXiv:0806.4412v2 [nucl-th] 4 Sep 2008.

K.S. Egiyan, et al.(JLAB), Phys. Rev. Lett.96, 082501 (2006).

A. B. Efremov, et al., Sov. J. Nucl. Phys. 47, 868 (1988).

Momentum distributions (• *and* o) of secondary protons from the reaction $^{12}C(p, p')X$ at 1 GeV



K=k1

$^{12}C(p, p'(nn))^{10}C$ m(^{12}C, free) =11174.866 MeV

m(**n**) - free = 939.565 MeV

m(**nn**) – free =1879.13 MeV m(^{10}C - free) = 9327.573 MeV

Q_{value} (**nn**) = -31.84 MeV

K3 = 0, **k1 = 1547 MeV/c**, Θ_{map}=21°, Θ_2=65.68°

m*(**nn**)=1190.01 MeV -36.67% (≈ 689 MeV)

K3*=0, k1=1483.5 MeV/c, Θmap=21.03°, **Parallel Kinematics : Θ2(0) = 59.78°, k2(0) = q_0 = 616.0 MeV/c.**

$^{12}C(p, p'(pp))^{10}Be$ m(**p**) - free = 938.272 MeV

m(**pp**)=1876.55 MeV m(^{10}Be - free) = 9325.504 MeV

Q_{value} (**nn**)= -27.183 MeV

K3 = 0, **k1 = 1552.38 MeV/c**, Θ_{map} = 21°, Θ_2 = 66.16°

m*(**pp**)=1146.07 MeV -38.93% (≈ 730.48 MeV)

K3*=0, k1=1483.1 MeV/c, Θmap=21.02°, **Parallel Kinematics : Θ2(0) = 59.74°, k2(0) = q_0 = 615.85 MeV/c.**

$^{12}C(p, p'\,^2H)^{10}B$ m(d = **pn**) – free =1875.613 MeV

m(^{10}B - free) = 9323.736 MeV

Q_{value} (d=**pn**)= -24.484 MeV

K3=0, **k1=1555.53 MeV/c**, Θ_{map}=21°, Θ_2=66.49°

m*(**pn**)=1125.37 MeV -40.00% (≈ 750.25 MeV)

K3*=0, k1=1483.1 MeV/c, Θmap=21.02°, **Parallel Kinematics : Θ2(0) = 59.75°, k2(0) = q_0 = 615.25 MeV/c.**

Результаты вычислений для реакций $^{12}C(p, p'(nn))^{10}C$, $^{12}C(p, p'(pp))^{10}Be$ и $^{12}C(p, p'\,^2H)^{10}B$

О. Миклухо

$^{12}C(p, p'(nn))^{10}C$

m(^{12}C, free) =11174.866 MeV ()

m(**nn**-free) =1879.13 MeV m(^{10}C - free) = 9327.573 MeV

Q_{value} (**nn**) = -31.838 MeV

m*(**nn**) = **1190.01** MeV (*)

-36.67% (≈ 689 MeV) m*(^{10}C)=10016.695 MeV

() **K3** = 0, k1=1546.98 MeV/c, Θmap=21°, Θ_2=65.68°, k2(0)=q(0)=608.362 MeV/c, T2=96.02 MeV

{ Parallel Kinematics }

(*) K3* = 0, **k1 = 1483.51** MeV/c, T1 = 817.05 MeV, Θmap = 21.027°, **{ k2(0) = q_0 = 616.0 MeV/c, Θ2(0) = 59.78° }**, T2(0) = 149.98 MeV

K3* = 0, **k1=1445 MeV/c**, Θ_i = Θmap=23.465°, Θ_2=57.31°, k2=683.67 MeV/c, T2=182.41 MeV

k3* ǂ 0, **k1=1483.27 MeV/c**, Θ_i = 23.465°, **k2(0) = 616.0 MeV/c, Θ2(0)=59.78°**

T2 = 149.98 MeV, **K3* = 63.11 MeV/c, Θ_3 = -67.54°, Θmap - Θ_3 = 91.01°**

K3* = 0, **k1=1521 MeV/c**, $\Theta_{i'}$=Θmap=18.453°, Θ_2=62.38°, k2=543.37 MeV/c, T2=118.18 MeV

k3* ǂ 0, **k1=1483.25 MeV/c**, $\Theta_{i'}$ =18.453°, **k2(0)=616.0 MeV/c, Θ2(0)=59.78°**

T2=149.98 MeV, **K3* = 66.65 MeV/c, Θ_3 = +109.5°, Θ_3 – Θmap = 91.06°**

$^{12}C(p, p'(pp))^{10}Be$

m(**pp**-free) =1876.55 MeV m(^{10}Be - free) = 9325.504 MeV

Q_{value} (**pp**) = -27.183 MeV

m*(**pp**) = **1146.07** MeV (*)

-38.93% (≈ 730.48 MeV) m*(^{10}Be)=10055.979 MeV

() **K3** = 0, k1=1552.38 MeV/c, Θmap=21°, Θ_2=66.16°, k2(0)=q(0)=608.075 MeV/c, T2=96.06 MeV

{ Parallel Kinematics }

(*) K3* = 0, **k1 = 1483.12** MeV/c, T1 = 816.72 MeV, Θmap = 21.019°, **{ k2(0) = q_0 = 615.85 MeV/c, Θ2(0) = 59.74° }**, T2(0) = 154.99 MeV

K3* = 0, **k1=1439 MeV/c**, Θ_i = Θmap=23.714°, Θ_2=56.90°, k2=690.83 MeV/c, T2=192.11 MeV

k3* ǂ 0, **k1=1482.83 MeV/c**, Θ_i =23.714°, **k2(0)=615.85 MeV, Θ2(0)=59.74°**

T2 = 154.99 MeV, **K3* = 69.76 MeV/c, Θ_3 = -67.40°, Θmap - Θ_3 = 91.11°**

K3* = 0, **k1=1527 MeV/c**, $\Theta_{i'}$ = Θmap=18.082°, Θ_2=62.84°, k2=532.70 MeV/c, T2=117.75 MeV

k3* ǂ 0, **k1=1482.78 MeV/c**, $\Theta_{i'}$ =18.082°, **k2(0)=615.85 MeV/c, Θ2(0)=59.74°**

T2 = 154.99 MeV, **K3* = 75.99 MeV/c, Θ_3 = +109.3°, Θ_3 – Θmap = 91.21°**

$^{12}C(p, p'\,^2H)^{10}B$

m(**pn**-free) =1875.613 MeV m(^{10}B - free) = 9323.736 MeV

Q_{value} (d=**pn**) = -24.484 MeV

m*(**pn**) = **1125.368** MeV (*)

-40.0% (≈ 750.25 MeV) m*(^{10}B)=10073.982 MeV

() **K3** = 0, k1=1555.53 MeV/c, Θ_{map}=21°, Θ_2=66.49°, k2(0)=q(0)=607.928 MeV/c, T2=96.06 MeV

{ Parallel Kinematics }

(*) K3* = 0, **k1=1483.1** MeV/c, T1 = 816.70 MeV, Θmap = 21.034°, **{ k2(0) = q_0 = 616.25 MeV/c, Θ2(0) = 59.748° }**, T2(0) = 157.68 MeV

K3* = 0, **k1=1433 MeV/c**, Θ_i = Θmap=24.035°, Θ_2=56.52°, k2=699.75 MeV/c, T2=199.81 MeV

k3* ǂ 0, **k1=1482.75 MeV/c**, Θ_i = 24.04°, **k2(0) = 616.25 MeV/c, Θ2(0) = 59.75°**

T2 = 157.68 MeV, **K3* = 77.66 MeV/c, Θ_3 = -67.20°, Θmap - Θ_3 = 91.24°**

K3* = 0, **k1=1533 MeV/c**, $\Theta_{i'}$ = Θmap=17.725°, Θ_2=63.32°, k2=522.34 MeV/c, T2=115.31 MeV

k3* ǂ 0, **k1=1482.67 MeV/c**, $\Theta_{i'}$ = 17.725°, **k2(0) = 615.25 MeV/c, Θ2(0) = 59.75°**

T2 = 157.68 MeV, **K3* = 85.83 MeV/c, Θ_3 = +109.1°, Θ_3 – Θmap = 91.37°**

Observation : k1 has the same value, ≈ 1483 MeV/c, in the Parallel Kinematics: **k2(0) ≈ 616.03 MeV/c, and Θ2(0) ≈ 59.76°**

2 Результаты вычислений для реакций $^{12}C(p, p'(nn))^{10}C$ и $^{12}C(p, p'(nnnn))^{8}C$

$^{12}C(p, p'(nn))^{10}C$

m(^{12}C, free) =11174.866 MeV

m(**nn**-free) =1879.13 MeV m(^{10}C - free) = 9327.573 MeV ()

Q_{value} (nn) = -31.838 MeV

m*(**nn**) = **1190.01** MeV (*)

-36.67% (≈ 689 MeV) m*(^{10}C)=10016.695 MeV

() **K3** = 0, k1=1546.98 MeV/c, Θmap=21^0, $Θ_2$=65.68^o, k2(0)=q(0)=608.362 MeV/c, T2=96.02 MeV

{ Parallel Kinematics }

(*) **K3*** = 0, **k1 = 1483.51** MeV/c, T1 = 817.05 MeV, Θmap = 21.027^o, **{ k2(0) = q_0 = 616.0 MeV/c, Θ2(0) = 59.78^o },** T2(0) = 149.98 MeV !!!

K3* = 0, **k1=1445 MeV/c**, $Θ_i$ = Θmap=23.465^o, $Θ_2$=57.31^o, k2=683.67 MeV/c, T2=182.41 MeV

k3*‡0, k1=1483.27 MeV/c, $Θ_i$ = 23.465^o, **k2(0) = 616.0 MeV/c, Θ2(0)=59.78^o**

T2 = 149.98 MeV, **K3* = 63.11 MeV/c, $Θ_3$ = -67.54^o, Θmap - $Θ_3$ = 91.01^o**

K3* = 0, **k1=1521 MeV/c**, $Θ_{i'}$=Θmap=18.453^o, $Θ_2$=62.38^o, k2=543.37 MeV/c, T2=118.18 MeV

k3*‡0, k1=1483.25 MeV/c, $Θ_{i'}$ =18.453^o, **k2(0)=616.0 MeV/c, Θ2(0)=59.78^o**

T2=149.98 MeV, **K3* = 66.65 MeV/c, $Θ_3$ = +109.5^o, $Θ_3$ – Θmap = 91.06^o**

$^{12}C(p, p'(nnnn))^{0}C$

m(**nnnn**-free) = 3758.26 MeV m(^{8}C - free) = 9327.573 MeV ()

Q_{value} (**nnnn**) = -67.344 MeV

m*(nnnn) = **1596.10** MeV (*)

-57.53% (≈ 2162 MeV) m*(^{8}C) = 9646.11 MeV ()

() **K3** = 0, k1=1560.645 MeV/c, Θmap=21^o, $Θ_2$=66.97^o, k2(0)=q(0)=607.7246 MeV/c, T2=48.82 MeV

{ Parallel Kinematics }

(*) **K3*** = 0, **k1 = 1483.477** MeV/c, T1 = 817.02 MeV, Θmap = 21.0007^o, **{ k2(0) = q_0 = 615.33** MeV/c, **Θ2(0) = 59.77^o },** T2(0) = 114.50 MeV !!!

K3* = 0, **k1=1445 MeV/c**, $Θ_i$ = Θmap=24.135^o, $Θ_2$=57.92^o, k2=700.366 MeV/c, T2=146.9 MeV

k3* ǂ 0, k1=1483.07 MeV/c, $Θ_i$ =24.135^o, **k2(0)=615.33 MeV, Θ2(0)=59.77^o**

T2 = 114.50 MeV, **K3* = 81.13 MeV/c, $Θ_3$ = -67.15^o, Θmap - $Θ_3$ = 91.29^o**

K3* = 0, **k1=1527 MeV/c**, $Θ_{i'}$ = Θmap=17.573^o, $Θ_2$=61.95^o, k2=520.35 MeV/c, T2=82.68 MeV

k3* ǂ 0, k1=1482.99 MeV/c, $Θ_{i'}$ =17.57^o, **k2(0)=615.23 MeV/c, Θ2(0)=59.77^0**

T2 = 114.50 MeV, **K3* = 88.73 MeV/c, $Θ_3$ = +108.97^o, $Θ_3$ – Θmap = 91.4^o**

Observation : k1 has the same value, ≈ 1483 MeV/*c*, in the Parallel Kinematics: **k2(0) ≈ 616.67 MeV/c, and Θ2(0) ≈ 59.78^o**

Результаты вычислений

$^{12}C(p, p' {}^{2}H)^{10}B$ m(**pn**) = **1875.613** MeV Q_{value} (d=**pn**) = -24.484 MeV m*(pn) = **1125.37** MeV -40.0% (≈ 750.25 MeV)

$^{12}C(p, p' (nn))^{10}C$ m(**nn**) = **1879.13** MeV Q_{value} (nn) = -27.183 MeV m*(**nn**) = **1190.01** MeV -36.67% (≈ 689 MeV)

$^{12}C(p, p' (nnnn))^{8}C$ m(**nnnn**) = **3758.26 MeV** Q_{value} (nn) = -67.344 MeV m*(**nnnn**) = **1596.1** MeV

$^{12}C(p, p' (pp))^{10}Be$ m(**pp**) = **1876.55** MeV Q_{value} (**pp**) = -31.838 MeV m*(pp) = **1146.07** MeV -38.93% (≈ 730.48 MeV)

Барионы (B = 1, L = 0)

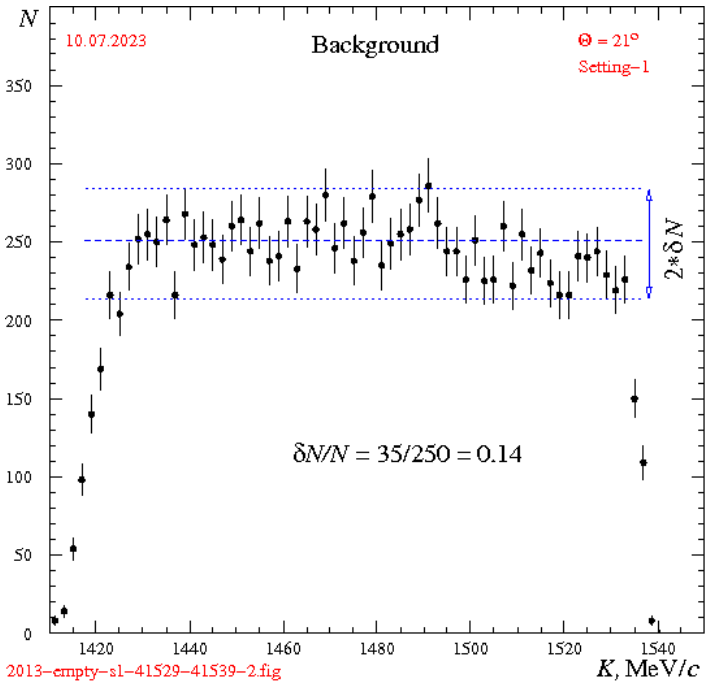
Частица	Кварковый состав	Масса, mc^2 (МэВ)	Время жизни (сек) или ширина (МэВ)	Спин-четность, изоспин $J^P(I)$	Основные моды распада
p	**uud**	**938.27**	**>1031 лет**	**$1/2^+(1/2)$**	
n	**ddu**	**939.57**	**887±2**	**$1/2^+(1/2)$**	**pe $\bar{\nu}$**
Λ	**uds**	**1116**	**$2.6\cdot10^{-10}$**	**$1/2^+(0)$**	**$p\pi^-$, $n\pi^0$**
Σ^+	**uus**	**1189**	**$0.80\cdot10^{-10}$**	**$1/2^+(1)$**	**$p\pi^0$, $n\pi^+$**
Σ^0	**uds**	**1193**	$7.4\cdot10^{-20}$	$1/2^+(1)$	Λγ
Σ^-	**dds**	**1197**	$1.5\cdot10^{-10}$	$1/2^+(1)$	$n\pi^-$

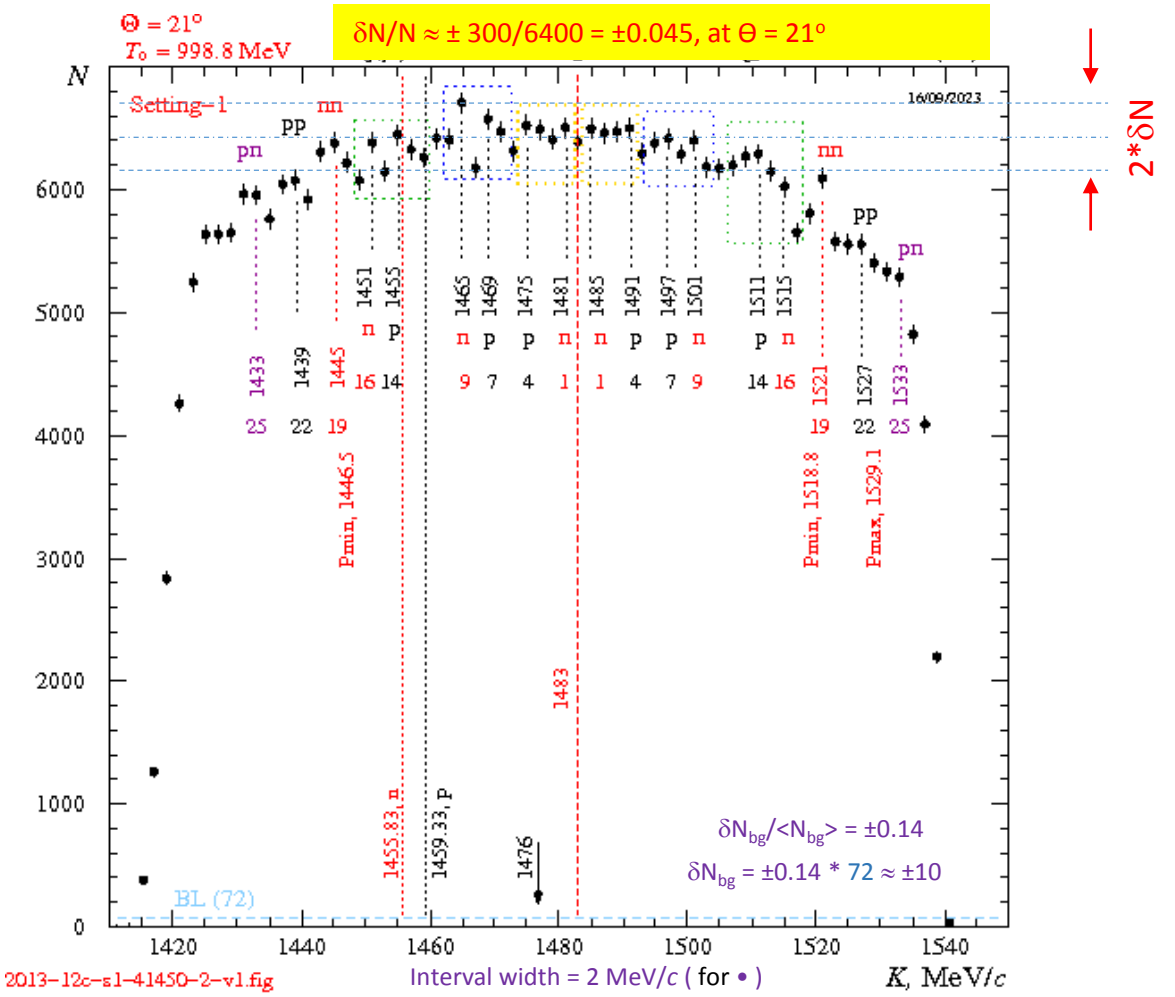
Мезоны (B=0, L=0)

π^+,π^-	**u , d**	**139.57**	**$2.6\cdot10^{-8}$**	**$0^-(1)$**	**$\nu\mu^+$, μ^- $\bar{\nu}$**
π^0	u -d	134.98	$8.4\cdot10^{-17}$	$0^-(1)$	2γ

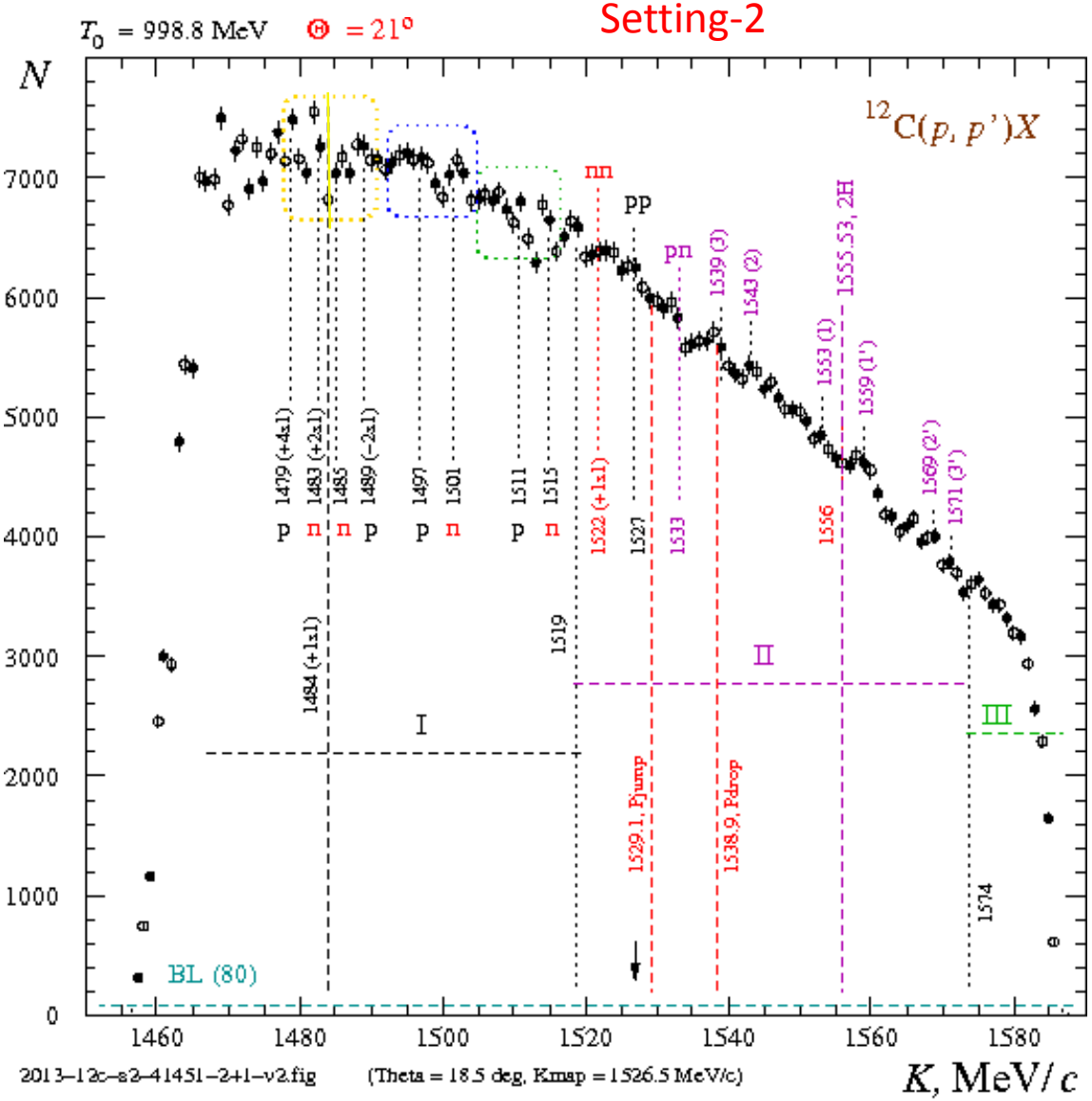
Приложение

Background investigation at Θ = 21°, Setting-1





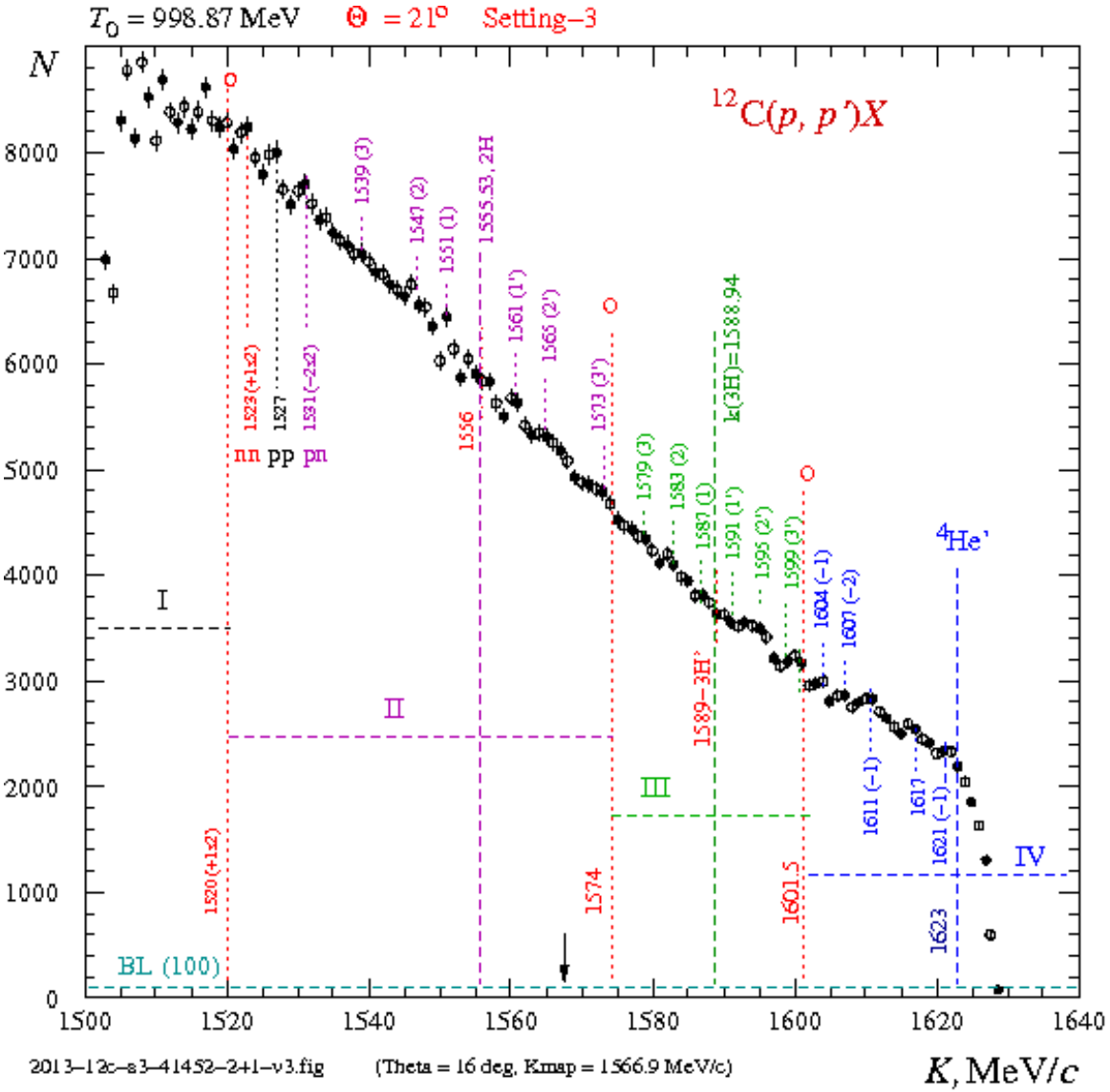
Momentum distributions (• *and* o) of secondary protons from the reaction $^{12}C(p, p')X$ at 1 GeV



K=k1

Interval width = 2 MeV/*c* (for • *and* for o)

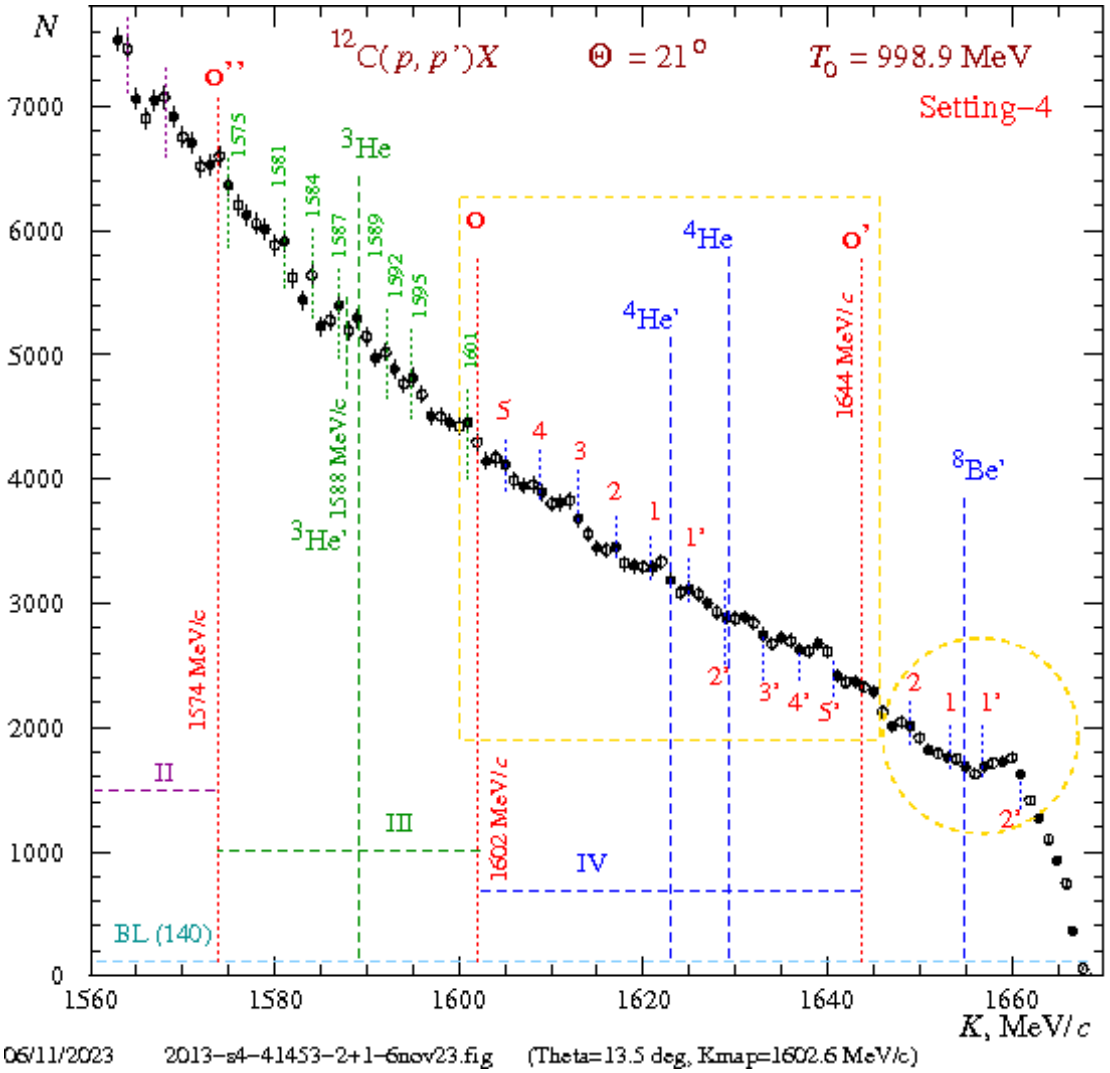
Momentum distributions (• *and* o) of secondary protons from the reaction $^{12}C(p, p')X$ at 1 GeV



K=k1

Interval width = 2 MeV/*c* (for • *and* for o)

Momentum distributions (• *and* o) of secondary protons from the reaction $^{12}C(p, p')X$ at 1 GeV



Interval width = 2 MeV/*c* (for • *and* for o)

K=k1

$\delta N_{bg}/\langle N_{bg}\rangle = \pm 0.14$

$\delta N_{bg} = \pm 0.14 * 140 \approx \pm 20$

Заключение

1. Обнаружены узкие пики в импульсном распределении вторичных протонов (ширина канала ΔK = 2 МэВ/c), рассеянных под углом 21^o в инклюзивной реакции (p, p') с ядром ^{12}C при энергии 1 ГэВ в области, охватывающей квазиупругий pN - пик. Пики расположены симметрично по импульсу относительно оси, примерно соответствующей упругому свободному pN – рассеянию (K_{pN} = 1483 МэВ/c). Группируются по два в трех импульсных интервалах, симметрично расположенных при $K > K_{pN}$ и $K < K_{pN}$. Причем два этих пика различаются по форме. Предполагается, что симметричный пик соответствует рассеянию протона пучка на ядерном нейтроне.

Наблюдаемая структура в импульсном распределении возможно связана с дифракционным упругим рассеянием протонов пучка на основных конституентах ядра ^{12}C - протонах и нейтронах. Симметрия обнаруженной структуры находится в соответствии с результатами исследования одночастичных уровней в деформированном ядре углерода методом квазиупругого (p, 2p) - и (p, pn) - рассеяния.

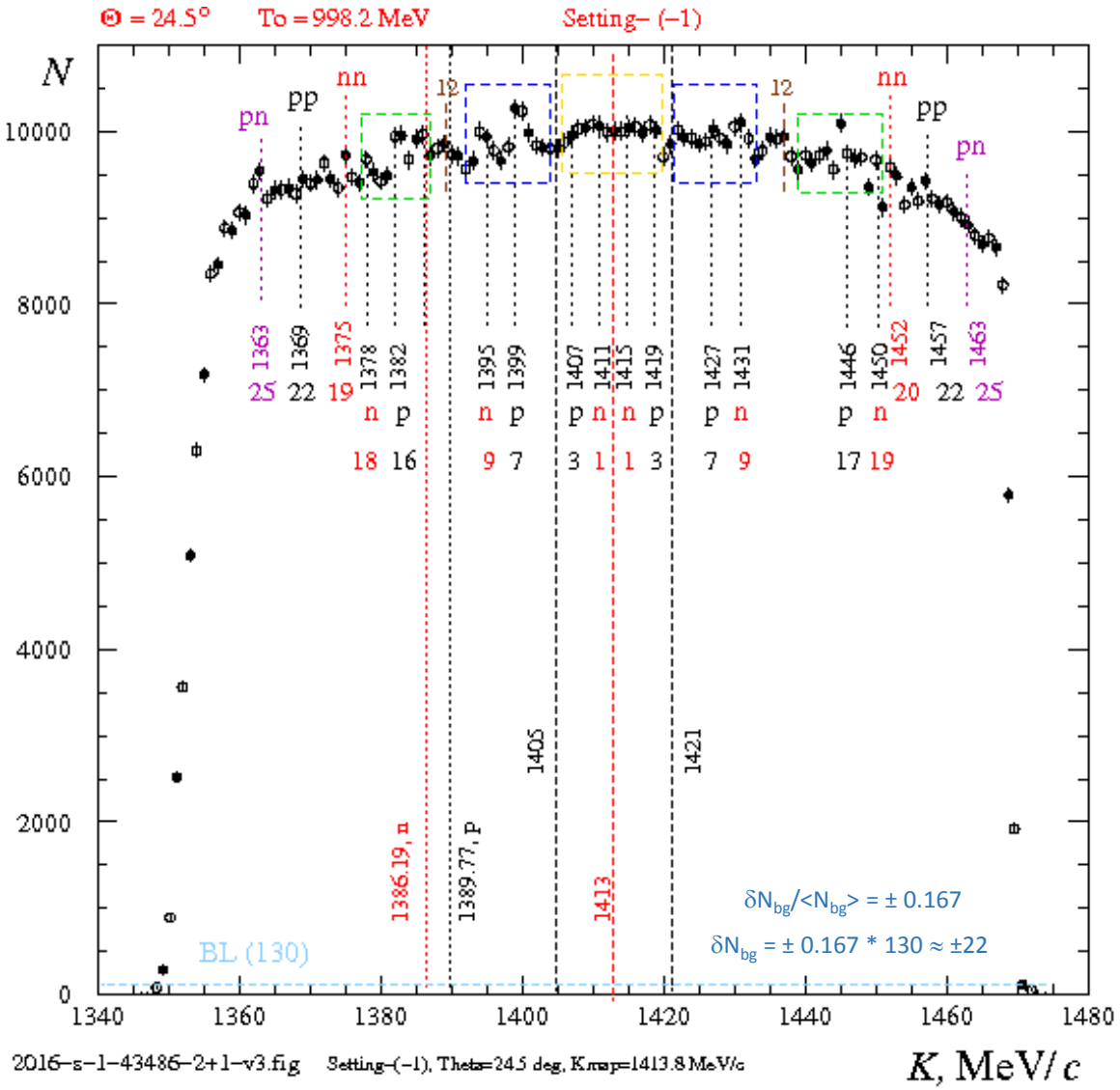
2. Проведен анализ возможной природы пиков, наблюдаемых вне области рассеяния на ядерных нуклонах и симметрично расположенных по импульсу относительно оси K_{pN} = 1483 МэВ/c. Проведены расчеты для случая дифракционного рассеяния на двухнуклонных корреляциях в ядрах.

СПАСИБО за ВНИМАНИЕ !

Дополнительные слайды

Measurements at $\Theta = 24.5^{o}$

Momentum distributions (• *and* o) of secondary protons from the reaction $^{12}C(p, p')X$ at 1 GeV

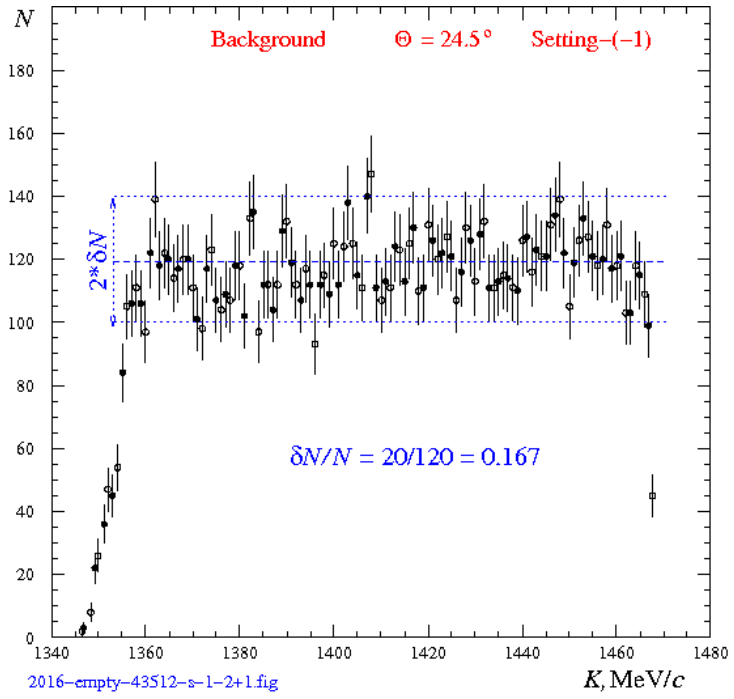


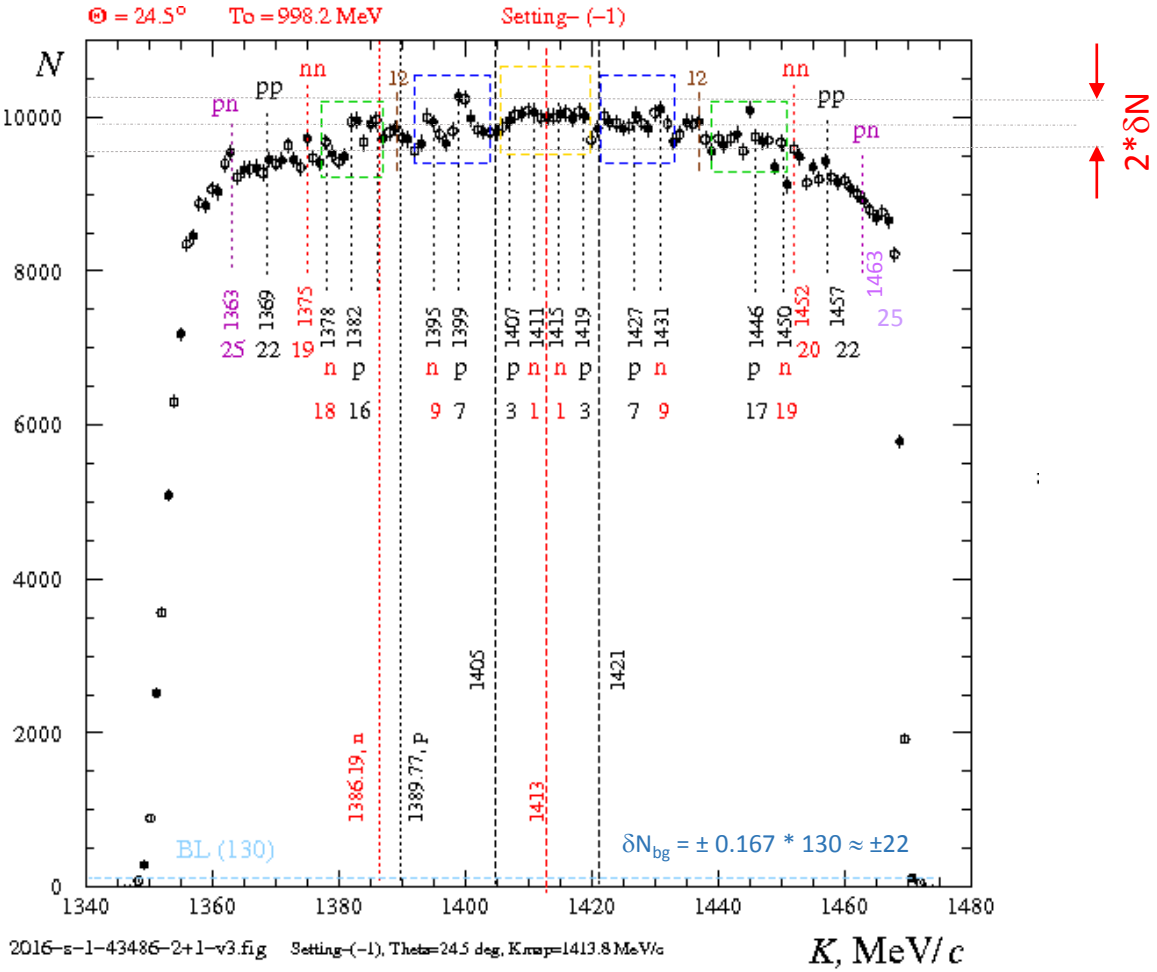
δN/N = ± 300/10000 = ± 0.03, at Θ = 24.5°

δN/N = ± 300/6400 = ±0.045, at Θ = 21°

Interval width = 2 MeV/*c* (for • *and* for o)

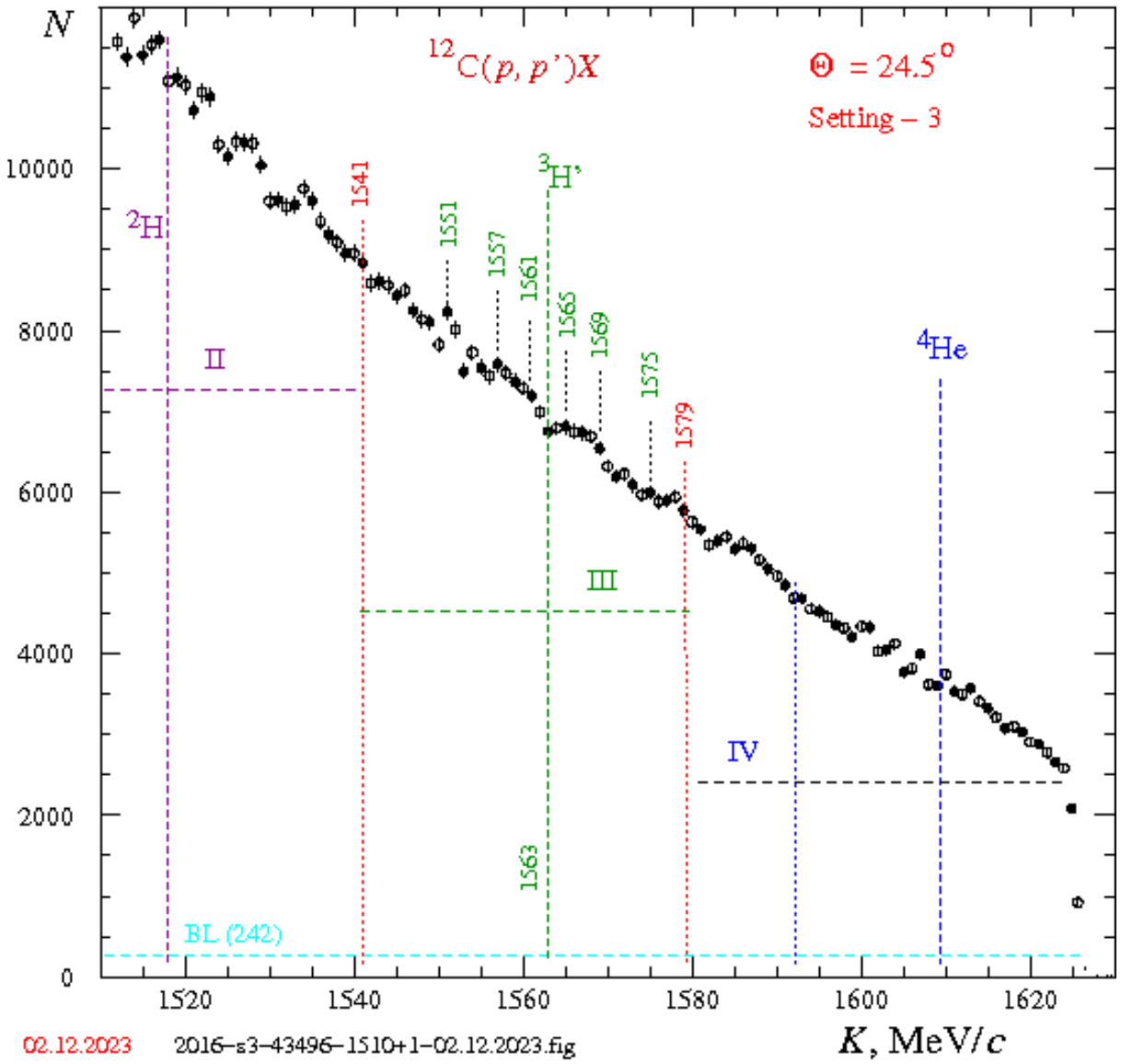
Background investigation at Θ = 24.5°, Setting-(-1)





δN/N = ± 300/10000 = ±0.03

Momentum distributions (• *and* ○) of secondary protons from the reaction $^{12}C(p, p')X$ at 1 GeV



Interval width = 2 MeV/*c* (for • *and* for ○)