THE HENRYK NIEWODNICZAŃSKI
INSTITUTE OF NUCLEAR PHYSICS
POLISH ACADEMY OF SCIENCES

Decay of the stretched resonance in ^{13}C studied by gamma-particle coincidences as a testing ground for Gamow Shell Model

Participants and collaboration

N. Cieplicka-Oryńczak, B. Fornal, M. Ciemała, M. Kmiecik, A. Maj, J. Łukasik, P. Pawłowski, B. Sowicki, B. Wasilewska, M. Zięblíński, I. Ciepał, M. Krzysiek, M. Matejska-Minda, K. Mazurek, W. Parol, B. Włoch, Y. Jaganathen
Institute of Nuclear Physics PAN, Kraków, Poland

S. Leoni, C. Boiano, S. Brambilla, S. Ziliani, S. Bottoni, A. Bracco, F. Camera, Ł. W. Iskra
University of Milan and INFN Sezione di Milano, Milan, Italy

M. N. Harakeh
KVI, Groningen, Netherlands

N. Marginean, C. Clisu, N. Florea, R. Marginean, L. Stan, I. Burducea, D. A. Iancu
IFIN-HH, Magurele, Romania

M. Sferazza
Universite libre de Bruxelles, Brussels, Belgium

M. Płoszajczak
GANIL, Caen, France

P. Kulessa
Institut für Kernphysik, Jülich, Germany

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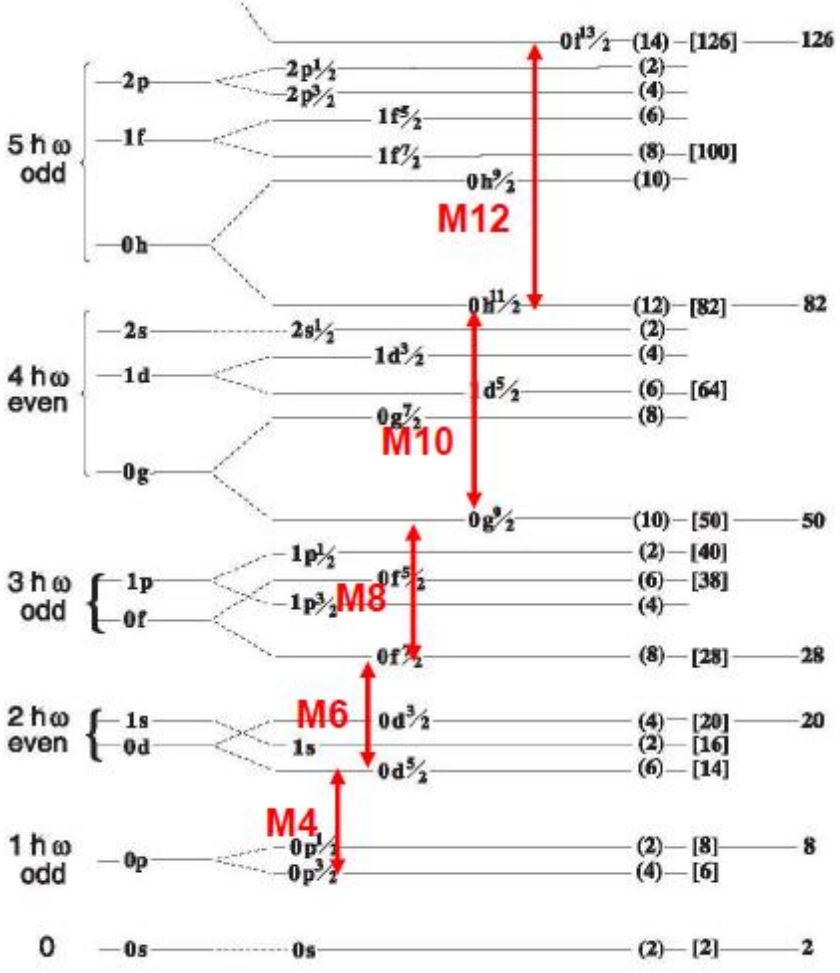
Outline

- What is a „stretched” state?
- ^{13}C – the first case studied at Cyclotron Centre Bronowice (Kraków, Poland)
- Experiment and results of analysis:
  - Scattered protons – gamma ray coincidences
  - Scattered protons – light charged particles coincidences
- Theoretical calculations within Gamow Shell Model – *Y. Jaganathen (IFJ PAN, Poland), M. Płoszajczak (GANIL, France)*

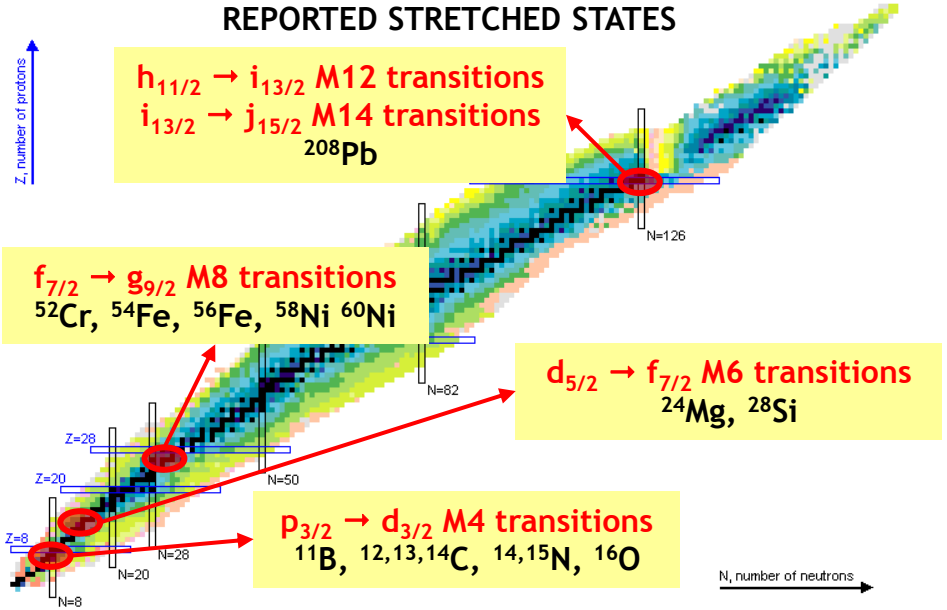


Stretched states

Such states are dominated by a single particle-hole component for which the excited particle and the residual hole couple to the maximal possible spin value:

$$J_{max} = j_p\ (max) + j_h\ (max)$$

REPORTED STRETCHED STATES



Stretched states in light nuclei (M4 resonances) – continuum region

CONFIGURATIONAL PURITY

simplest known nuclear excitations providing

clean information on the details of nuclear force

TESTING GROUND FOR THEORETICAL CALCULATIONS

properties of stretched states (decay patterns e.g.) used as

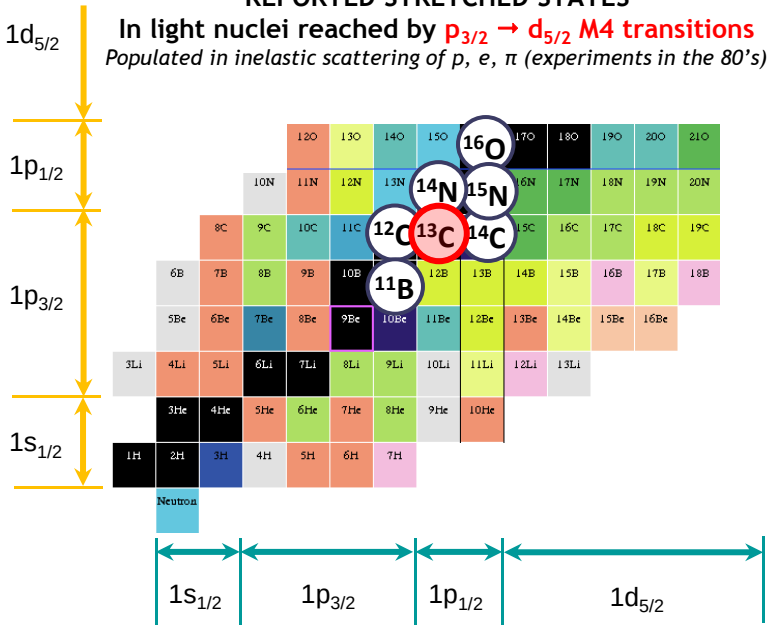
demanding test of state-of-the-art theory approaches

(Gamow Shell Model e.g.)

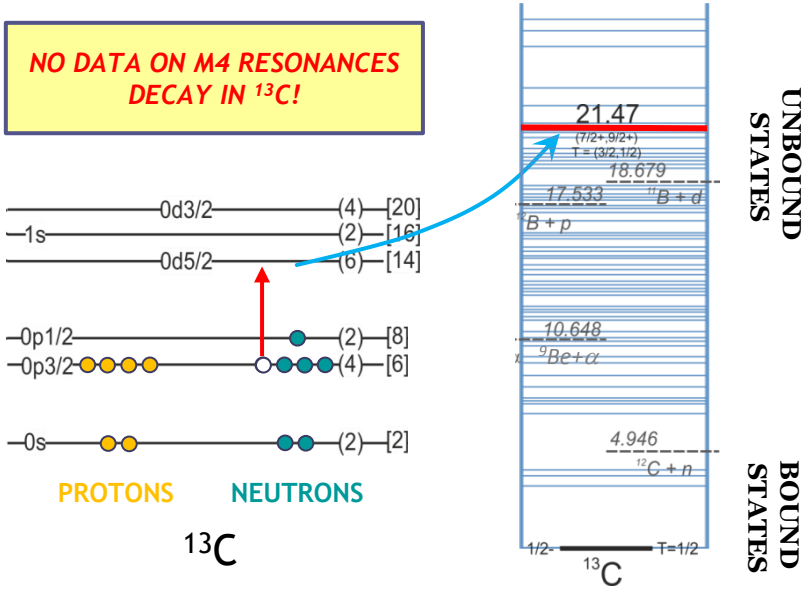
REPORTED STRETCHED STATES

In light nuclei reached by $p_{3/2} \rightarrow d_{5/2}$ M4 transitions

Populated in inelastic scattering of p, e, π (experiments in the 80's)

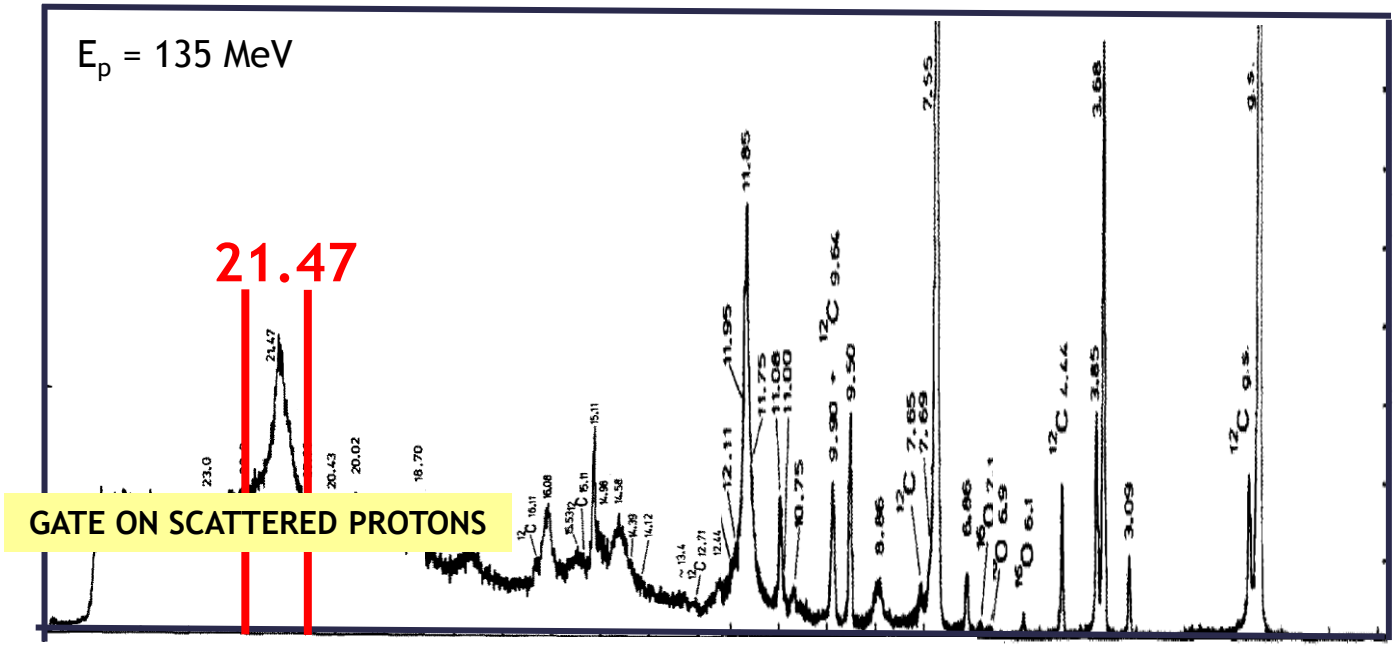


NO DATA ON M4 RESONANCES DECAY IN ^{13}C!



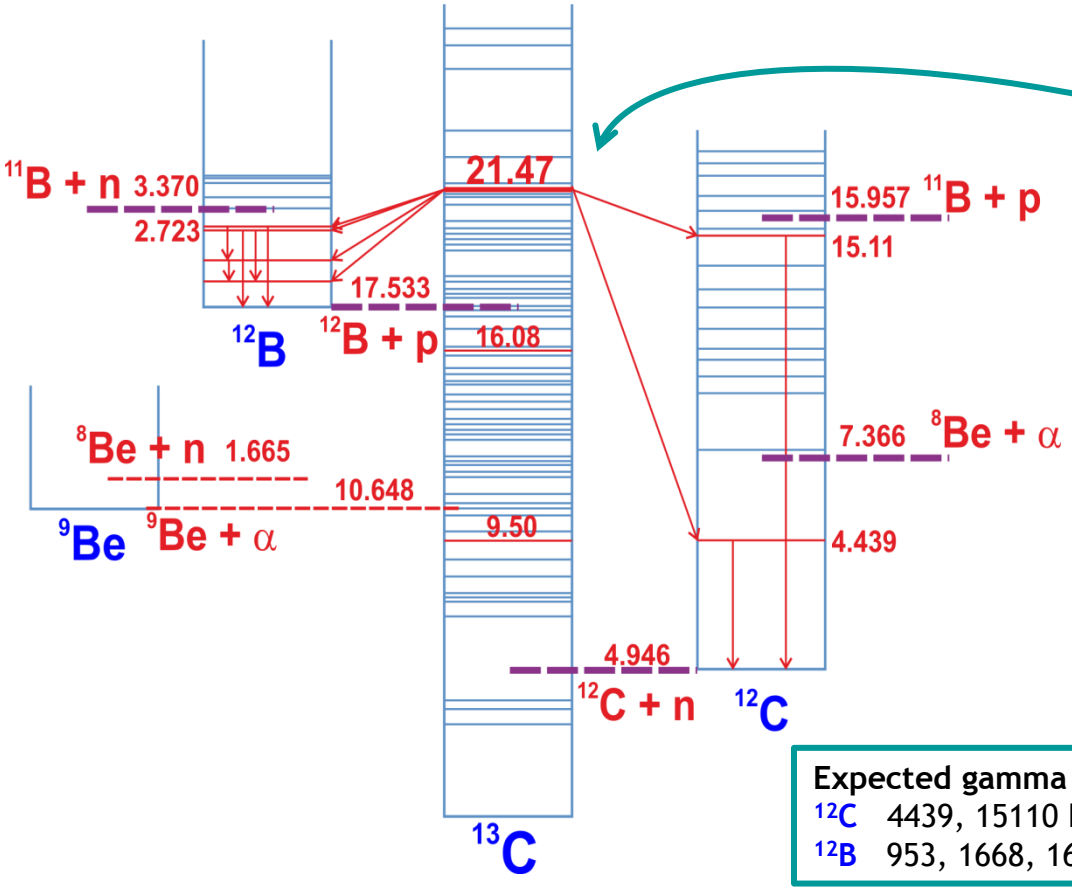
Previous studies of stretched states in ^{13}C

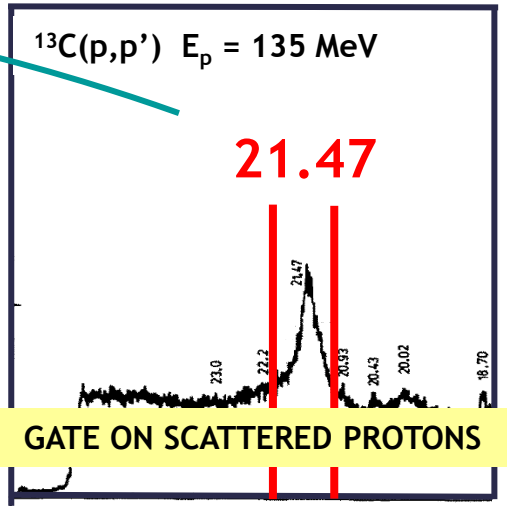
Inelastic proton scattering on ^{13}C



Indiana University Cyclotron Facility Magnetic Spectrograph, S.F. Collins et al., Nuc. Phys. A481, 494(1988)

Expected decay scheme of the 21.5-MeV M4 resonance in ^{13}C

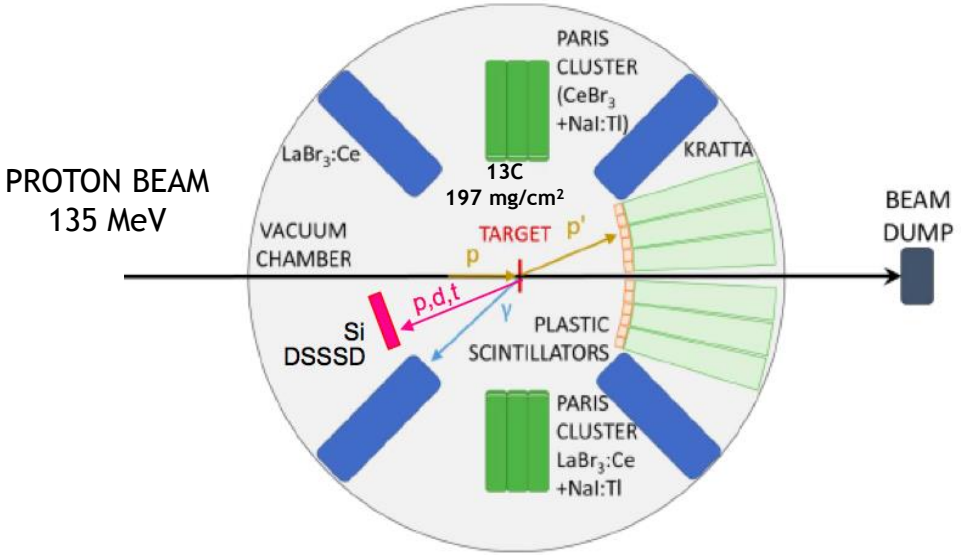


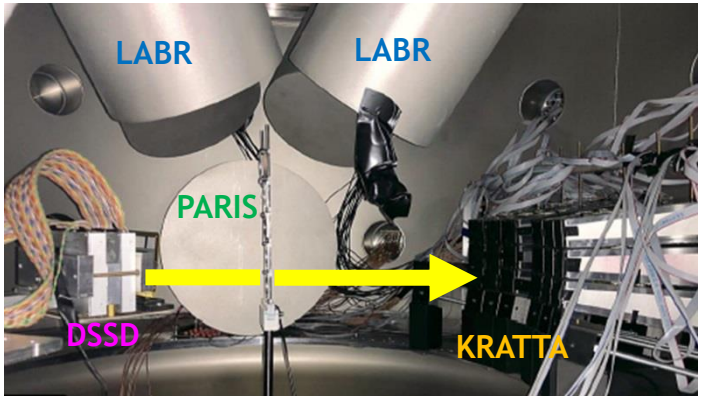


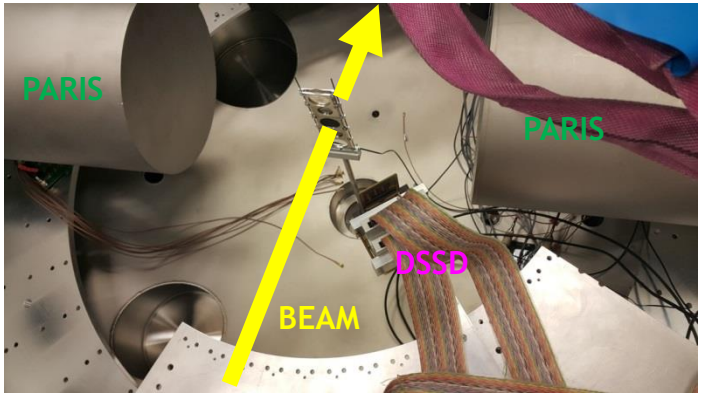
S.F. Collins et al., Nuc. Phys. A481, 494(1988)

Expected gamma rays:
^{12}C 4439, 15110 keV
^{12}B 953, 1668, 1674, 2723 keV

Experimental setup – Cyclotron Centre Bronowice (Kraków, Poland)

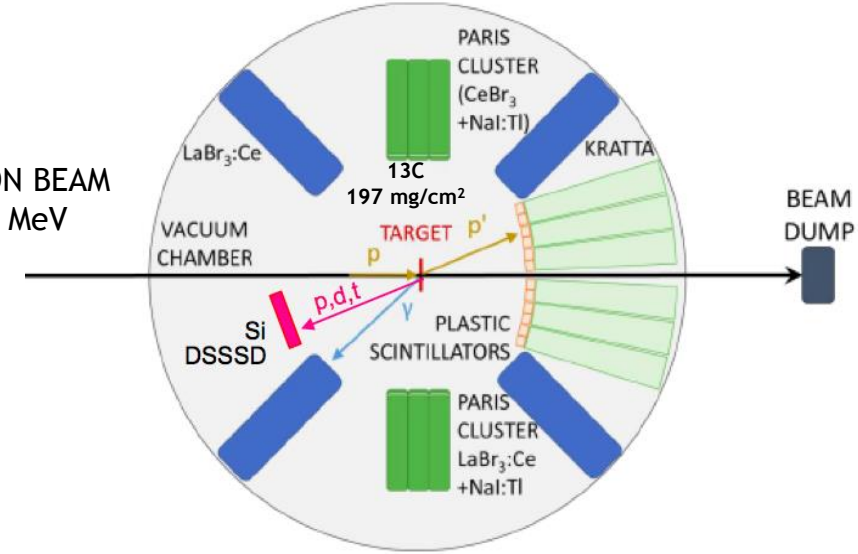


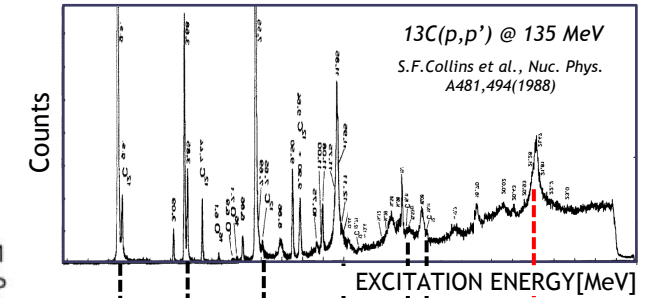




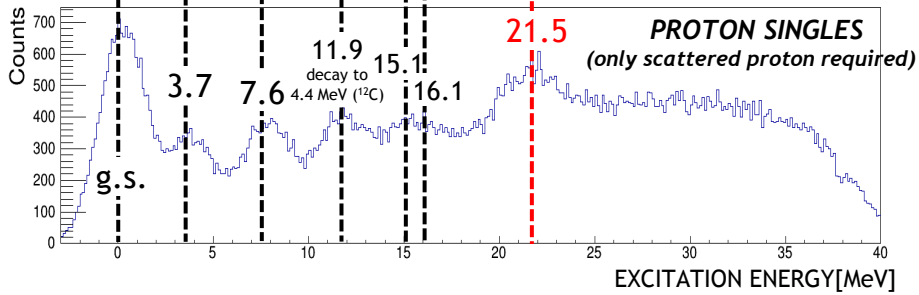
1) Scattered protons measurement: KRATTA telescope array
2) γ-ray detection:
   - four $LaBr_3$ detectors (3”x3”)
   - two clusters of the PARIS scintillator array
3) Measurement of light charged particles produced in the reaction: a thick position-sensitive Si detector

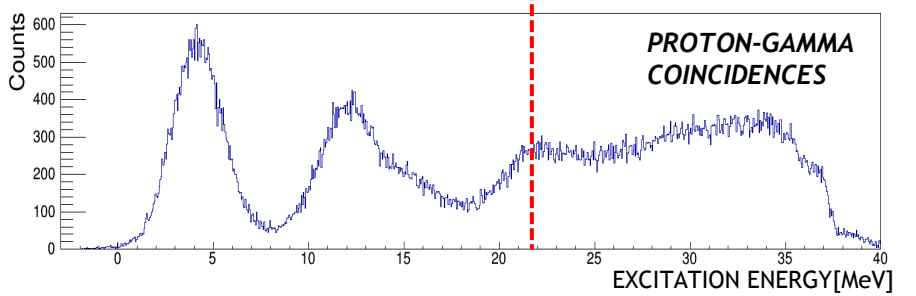
KRATTA – excitation energy spectra measured at ~36°





REFERENCE SPECTRUM





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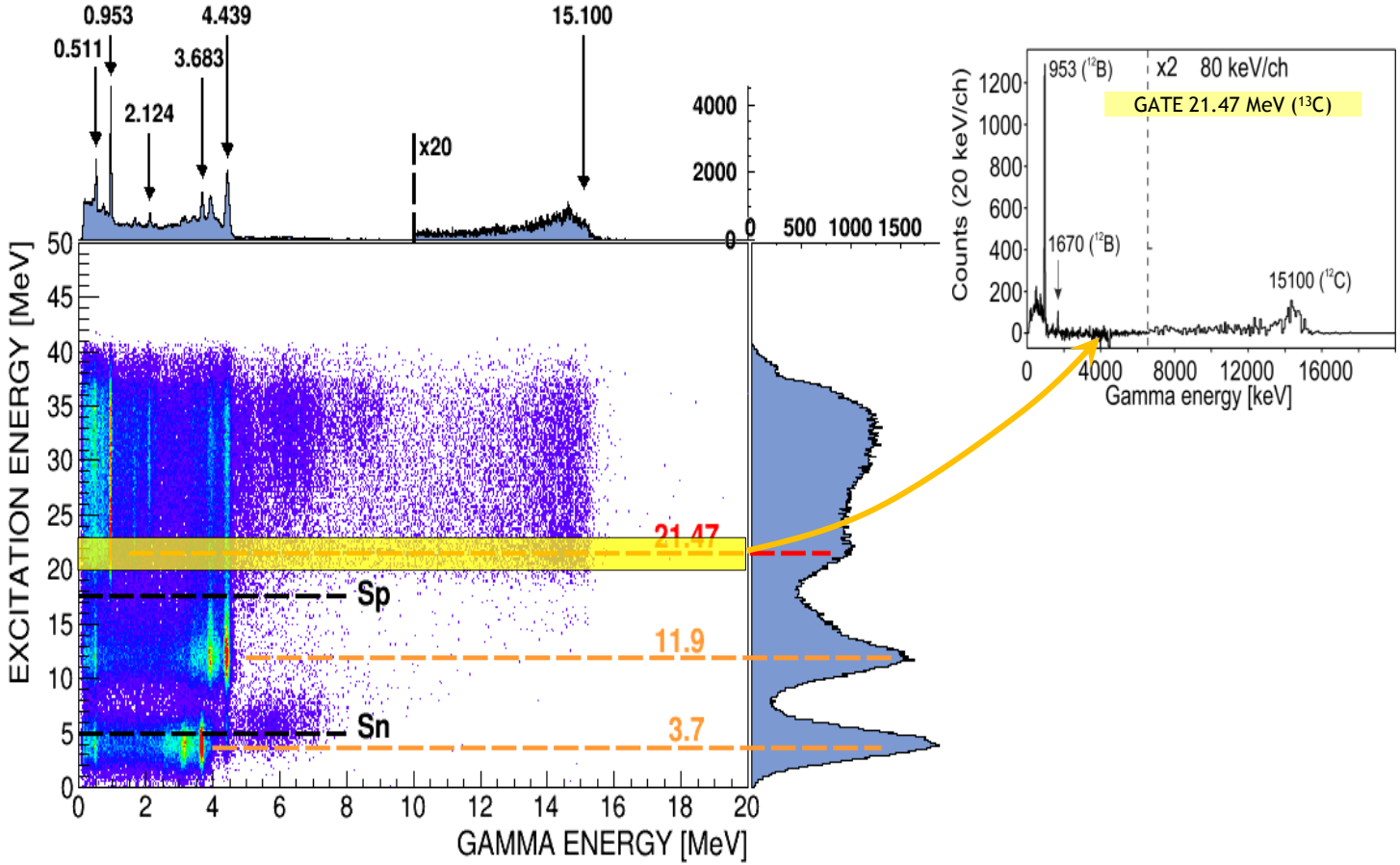
Experimental results: proton-gamma coincidence measurement



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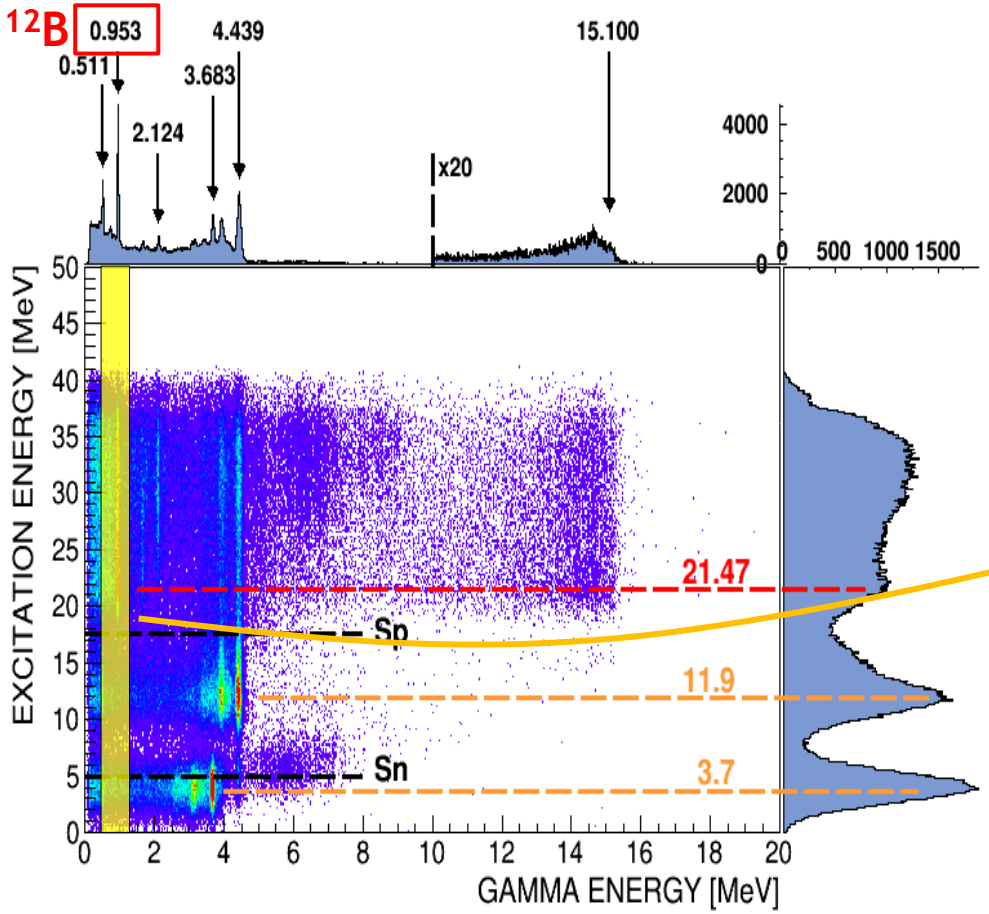

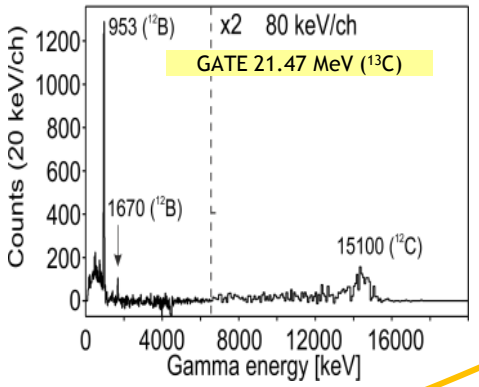

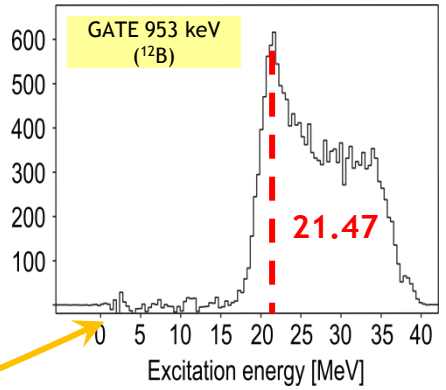

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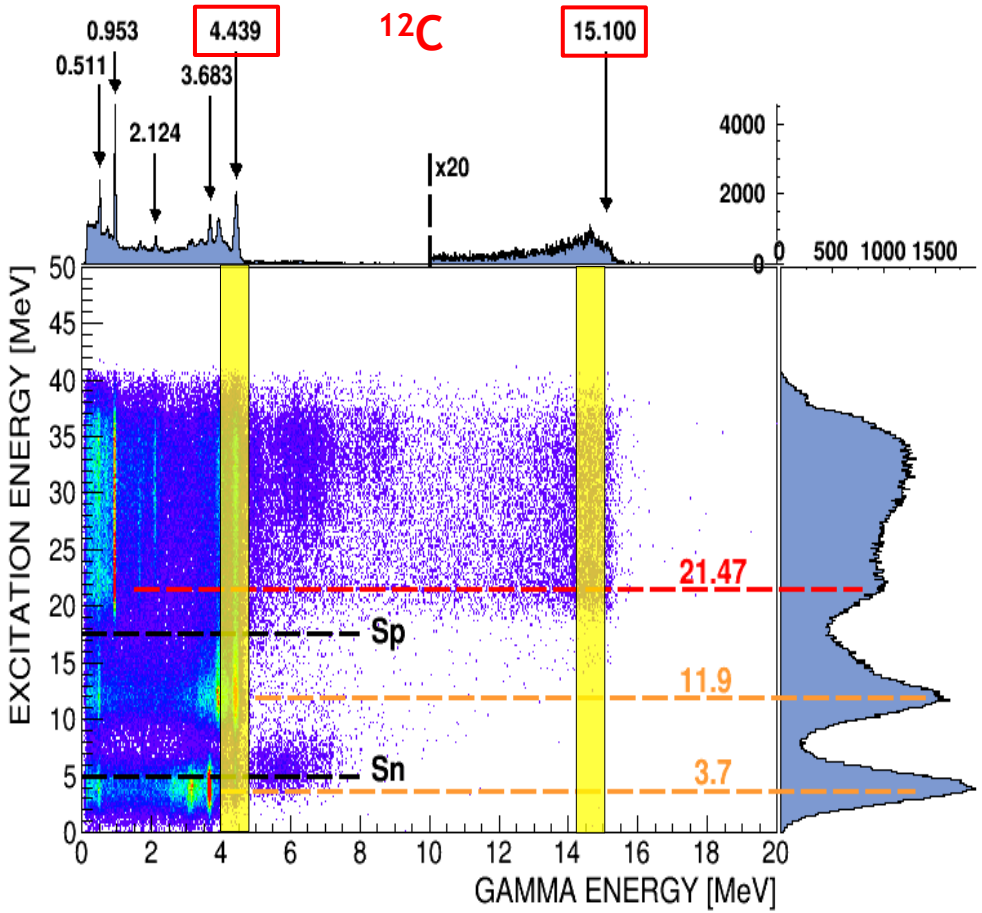
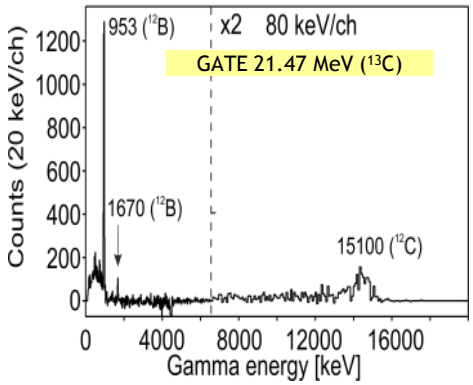
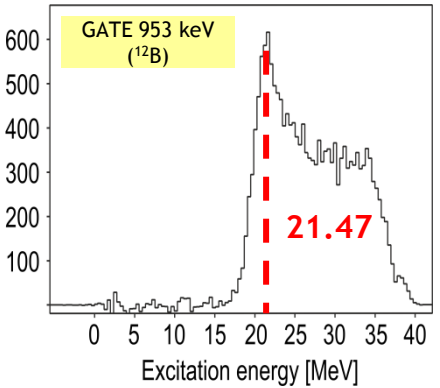
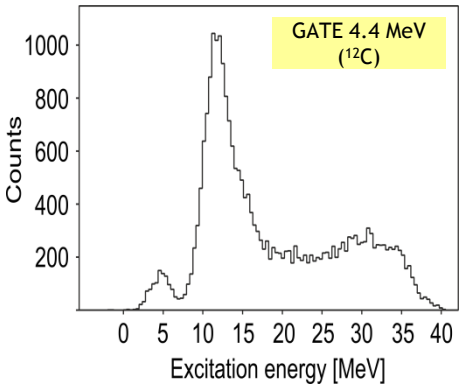
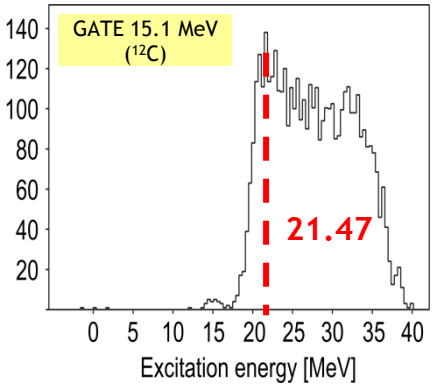


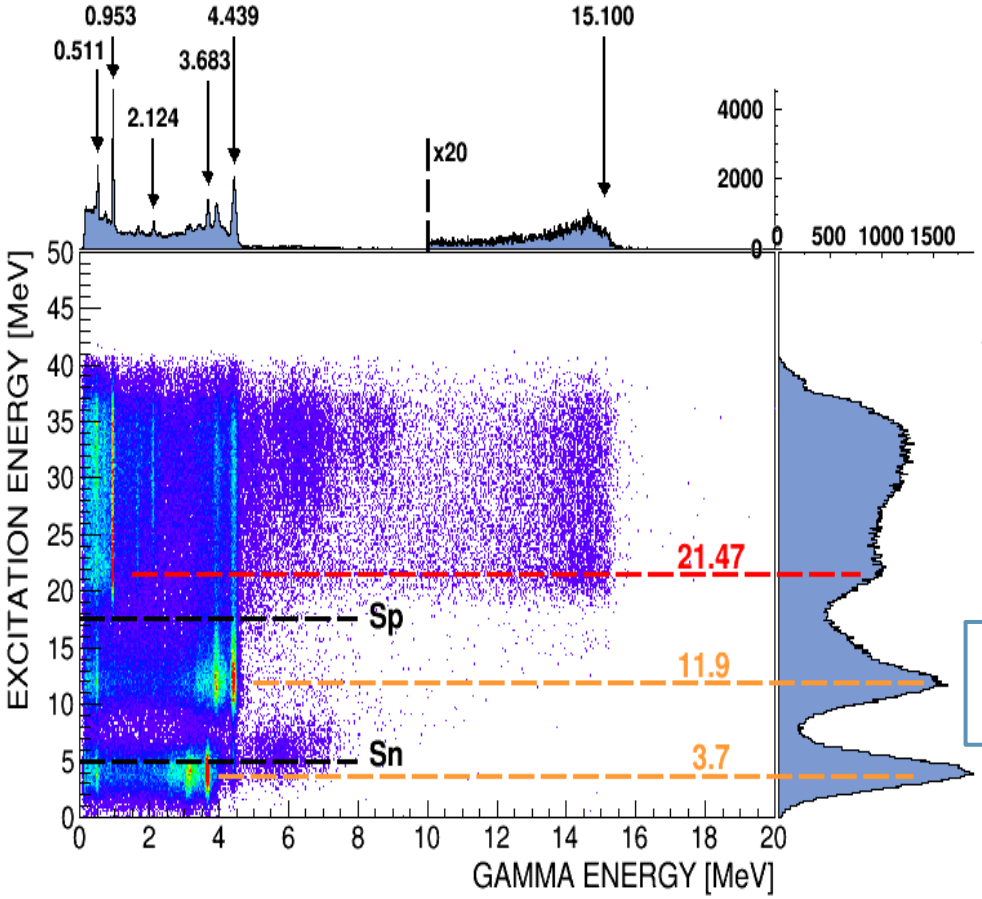


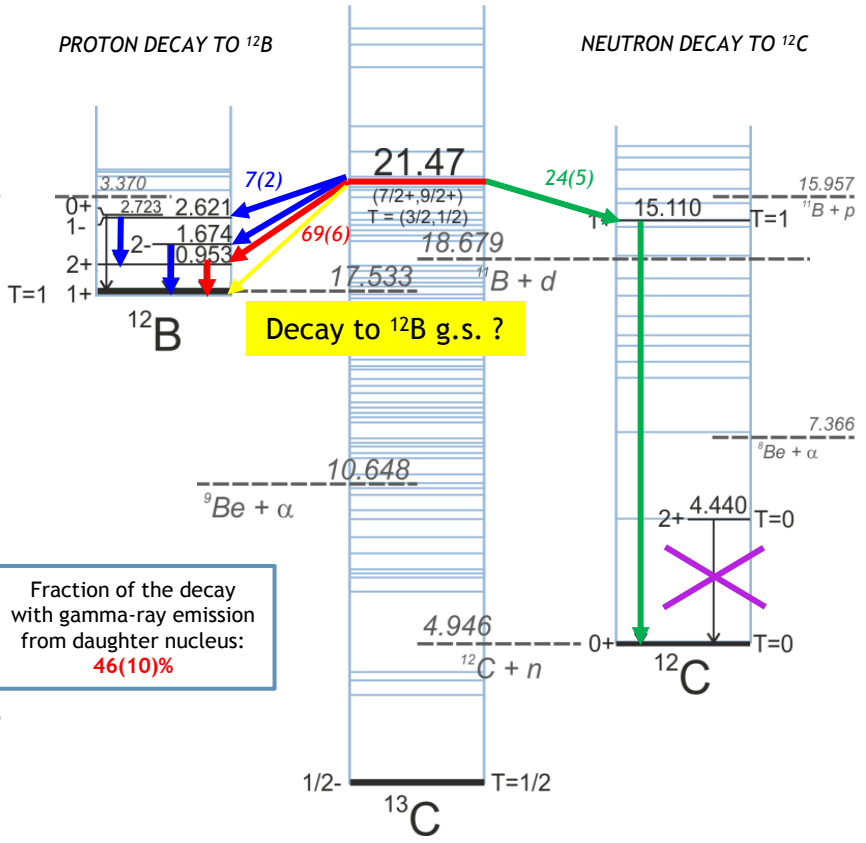






Experimental results: proton-gamma coincidence measurement





Experimental results: proton-proton coincidence measurement

TEST EXPERIMENT WITH THIN TARGET FOR LOW-ENERGY PROTONS

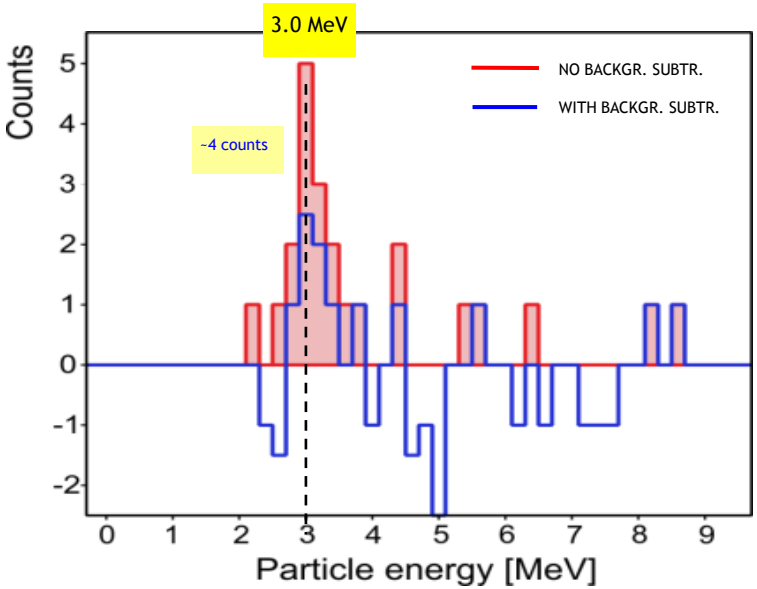
^{13}C target made of 10 foils in separate frames, total thickness 1 mg/cm^2

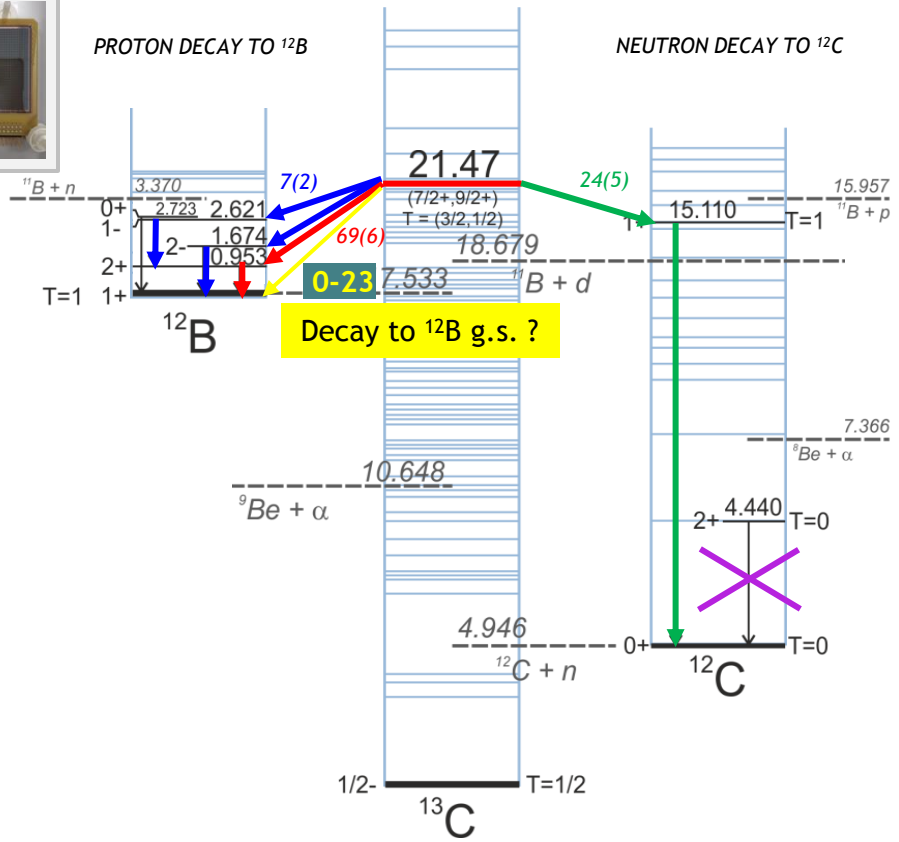
Nicoleta Florea, Nicu Marginean IFIN-HH, Romania

DSSSD (Micron Semiconductor Ltd)

Active area: 50mm x 50mm
No. of strips: 32 (16 per side)
Thickness: 1.5 mm

LIGHT PARTICLE IDENTIFICATION BASED ON ENERGY AND RISE TIME





Stretched states in the continuum – Gamow Shell Model calculations

The Gamow Shell Model is an open-quantum system extension of the traditional Shell Model, which provides a rigorous treatment of the many-body correlations and the coupling to the resonant and non-resonant particle continuum.

Calculations by Y. Jaganathen (IFJ PAN) and M. Płoszajczak (GANIL)

- Model space **specifically adapted** to describe the M4 state:
  - an **effective** ^{4}He core modeled by a Woods-Saxon + spin-orbit + Coulomb terms
  - 3 effective holes max. in the ^{12}C core
  - *psdf*$_{7/2}$ model space
  - an effective finite-range NN potential with **central, spin-orbit and tensor terms**
- The depths of the one-body potential and the 8 parameters of the NN interaction were adjusted to the low-lying spectra of ^{12}B, ^{12}C, ^{12}N, ^{13}C, ^{13}N, as well as ^{14}C, ^{14}N, ^{14}O

FOR THE FIRST TIME GSM CALCULATIONS WERE PERFORMED FOR SUCH „HEAVY" SYSTEM

State	E_{calc} (MeV)	E_{exp} (MeV)
^{12}B, 1-, T=1	2.467*	2.261
^{12}B, 2-, T=1	1.368*	1.674
^{12}B, 2+, T=1	0.749*	0.953
^{12}B, 1+, T=1	-0.164*	0.0
^{12}C, 2+, T=1	16.767(4)	16.106
^{12}C, 1+, T=1	15.667(4)	15.11
^{12}C, 2+, T=0	4.81*	4.44

(*) fitted

CANDIDATES FOR THE 21.5-MeV M4 RESONANCE IN ^{13}C:

$J=7/2^+$	T=3/2	E = 21.832 MeV	Γ = 400(500) keV
$J=9/2^+$	T=3/2	E = 22.594 MeV	Γ = 150(300) keV

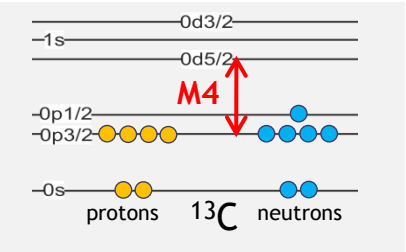
Stretched states in the continuum – Gamow Shell Model calculations

(by Y. Jaganathen (IFJ PAN) and M. Płoszajczak (GANIL))

21.832 MeV 7/2⁺
T = 3/2

P: $(0p_{3/2})^3$ $(0d_{5/2})^1$ N: $(0p_{3/2})^4(0p_{1/2})^1$ 24%	P: $(0p_{3/2})^3$ $(0p_{1/2})^1$ N: $(0p_{3/2})^4(0d_{5/2})^1$ 20%	P: $(0p_{3/2})^4$ N: $(0p_{3/2})^3(0p_{1/2})^1(0d_{5/2})^1$ 19%

^{13}C



0.749 MeV 2⁺
T = 1

P: $(0p_{3/2})^3$ N: $(0p_{3/2})^4(0p_{1/2})^1$ 64%

15.667 MeV 1⁺
T = 1

P: $(0p_{3/2})^3(0p_{1/2})^1$ N: $(0p_{3/2})^4$ 32%	P: $(0p_{3/2})^4$ N: $(0p_{3/2})^3(0p_{1/2})^1$ 33%

-0.164 MeV 1⁺
T = 1

P: $(0p_{3/2})^3$ N: $(0p_{3/2})^4(0p_{1/2})^1$ 62%

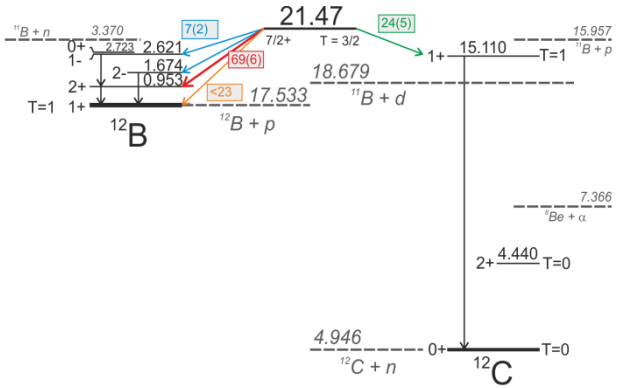
^{12}B

ISOSPIN FORBIDDEN

4.81 MeV 2⁺
T = 0

P: $(0p_{3/2})^3(0p_{1/2})^1$ N: $(0p_{3/2})^4$ 33%	P: $(0p_{3/2})^4$ N: $(0p_{3/2})^3(0p_{1/2})^1$ 33%

^{12}C



Summary

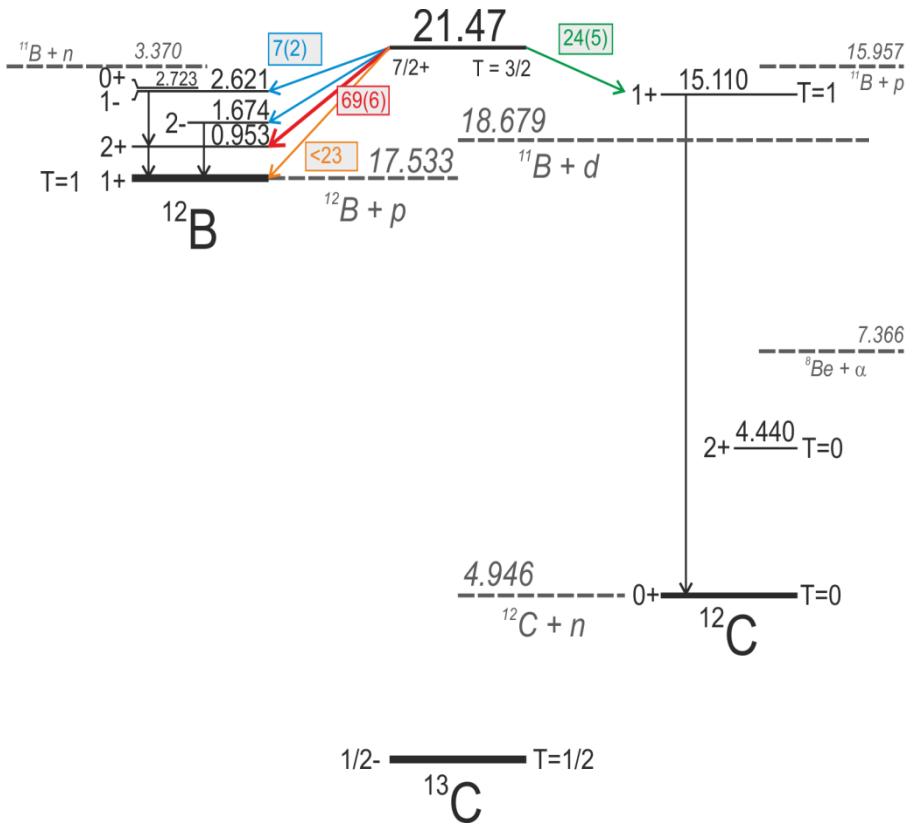
The first information on the **decay branching of the 21.47-MeV stretched state in ^{13}C** nucleus was obtained from proton-gamma coincidence measurements.

For the first time **Gamow Shell Model calculations** are being performed for such „heavy” system.

Comparisons with experiment in terms of **states energies and decay branchings** are being performed for the first time and they seem to be successfull.

Better understanding of the decay pattern!

This newly developed approach will be crucial in predicting structures in the continuum in other nuclei in this key region of nuclear chart.



Thank you for your attention!