Past, Present and Future of Shell Model
26, Jan. – 28, Jan. 2006, CNS Workshop

Measurement of the $^{19}C(p,p')$ reaction at E_p=70 MeV

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Introduction

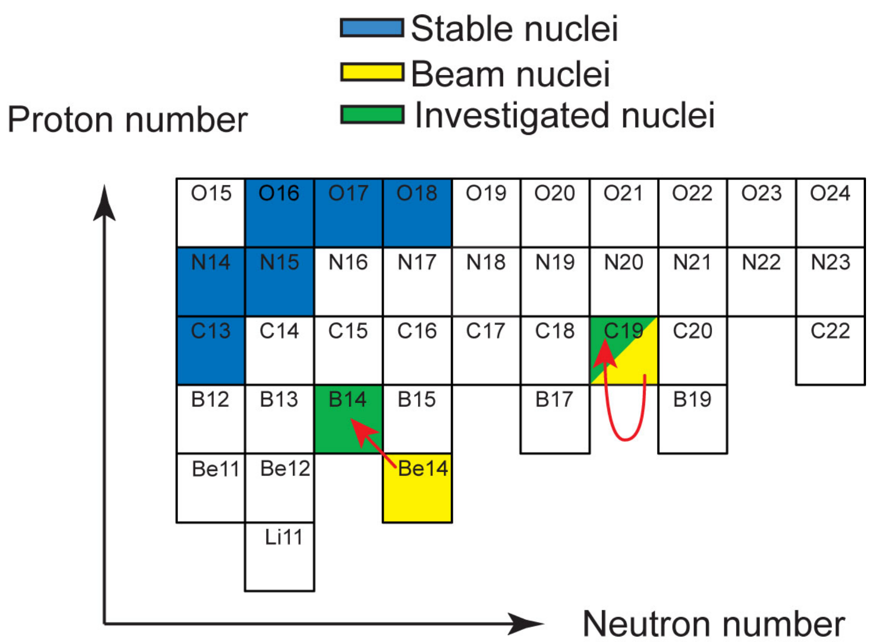
General Purpose

- Nucleon-induced reactions, (p,p') and (p,n), have been one of the major tools to study nuclear structures.
  - Various combinations of ΔS(spin), ΔT(isospin), Δq, ΔE are available. => Populating various types of excited states.
  - Many theoretical works done to reproduce cross sections.

    => Allowing to make a detailed study of the wave function through the transition density.

- In order to extend such studies to unstable nuclei, we are developing an experimental method of spectroscopy involving neutron detection in inverse kinematics.

- $^{19}C(p,p')$ at E_p=70 MeV

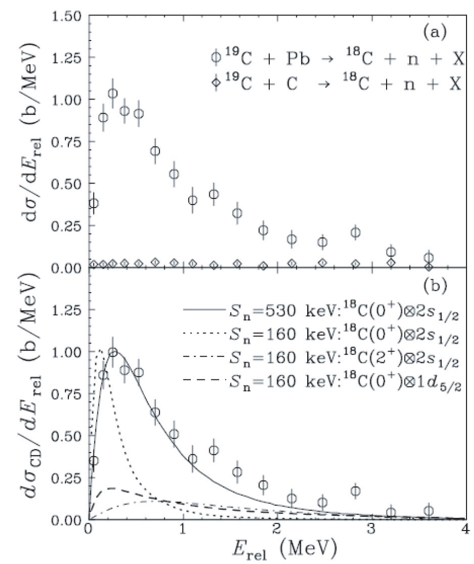


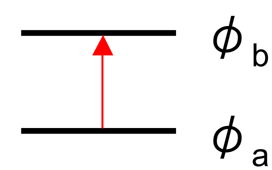
Physics Motivation Related to ^{19}C

^{19}C: Candidate of the heaviest one-neutron halo nucleus

- To clarify the ground state property of ^{19}C.
  - Longitudinal momentum distribution of ^{18}C after the one-neutron removal from ^{19}C
    - D.Bazin et al. PRL74(1995)3569. 1/2+
    - T.Baumann et al. PLB439(1998)256. 5/2+
  - Coulomb Dissociation of ^{19}C
    - T.Nakamura et al. PRL83(1999)1112. 1/2+
  - Single-nucleon knockout reaction, partial cross sections to final states of the ^{18}C residue
    - V.Maddalena et al. PRC63(2001)024613. 1/2+

T.Nakamura et al.





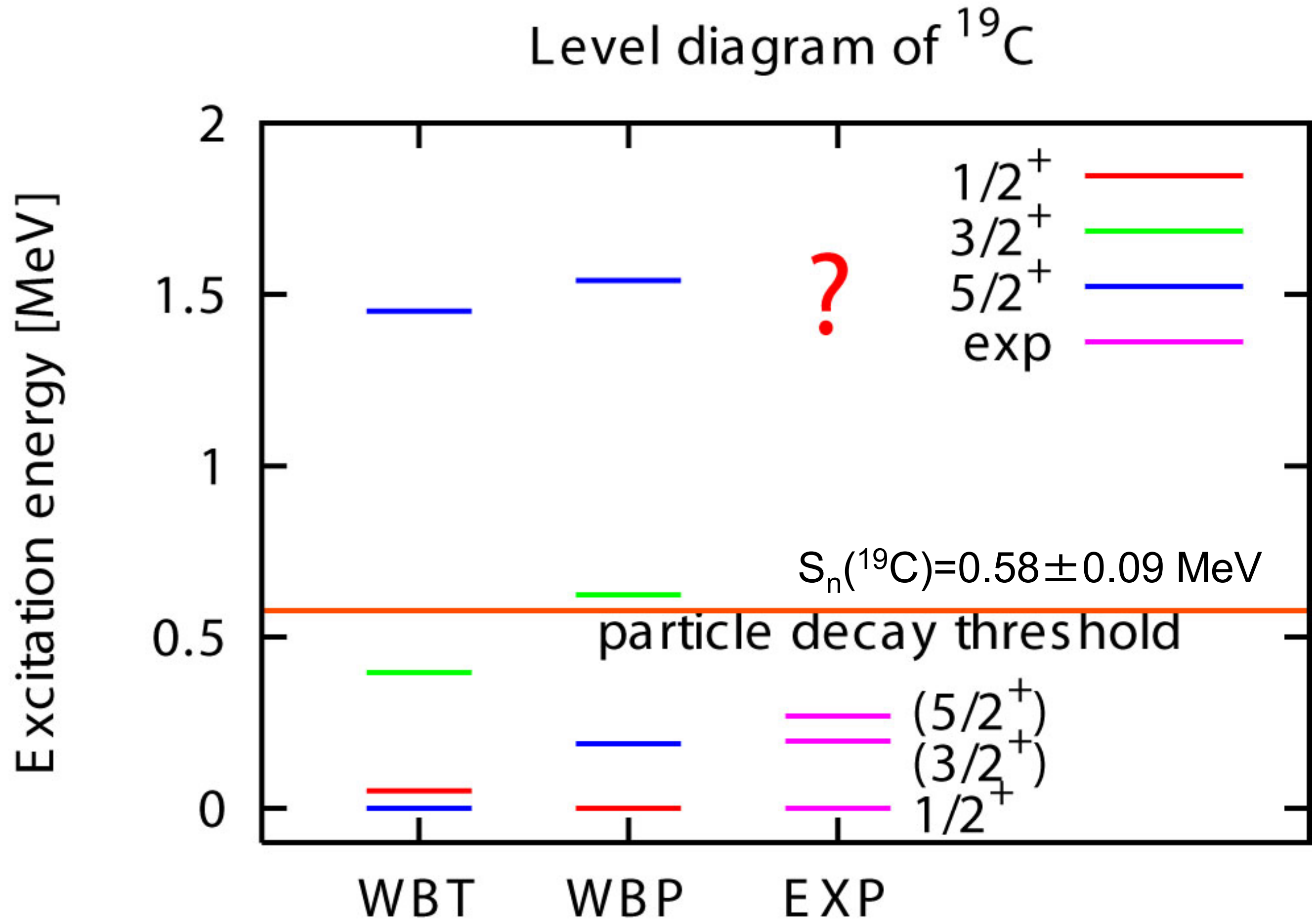
①Identify excited states in ^{19}C.

②Using the (p,p') cross section as a probe, specify the structure of the ground state.

$$\frac{d\sigma}{d\Omega} = \frac{m_a m_b}{(2\pi\hbar^2)^2}\frac{k_b}{k_a}|T_{ba}|^2$$

$$T_{ba} = \langle \varphi_b | V_b | \varphi_a \rangle$$

Known Excited States in ^{19}C

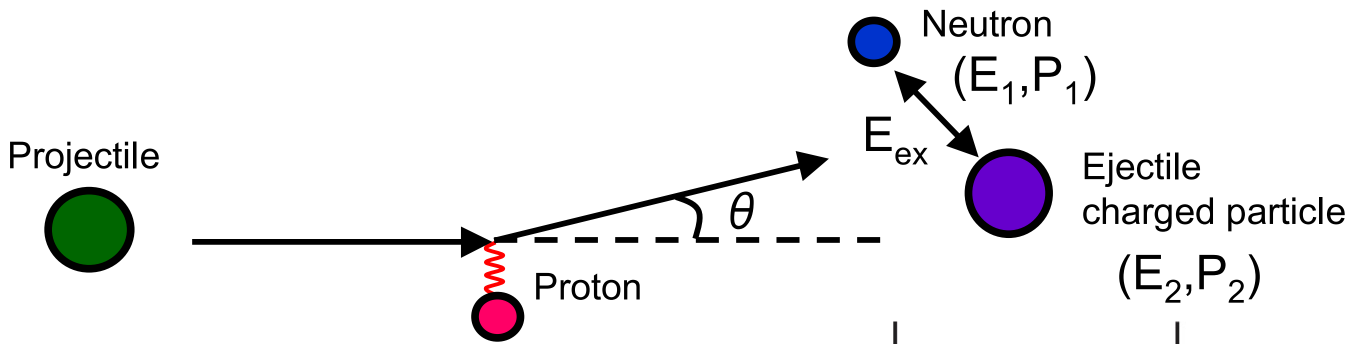


EXP: Z.Elekes et al. PLB614(2005)174.
R.Kanungo et al. NPA 757(2005)315. => No isomers observed.

No excited states known above the neutron decay threshold !

Experiment and Analysis

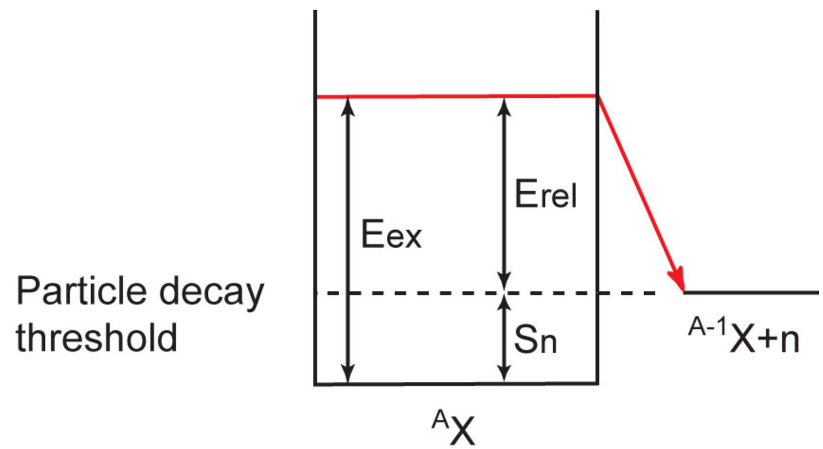
Invariant Mass Method in Inverse Kinematics



$$M_{IV} = \sqrt{(\sum_i E_i)^2 - |\sum_i \vec{P}_i|^2}$$

$$E_{rel} = M_{IV} - \sum_i M_i$$

$$E_{ex} = E_{rel} + S_n$$

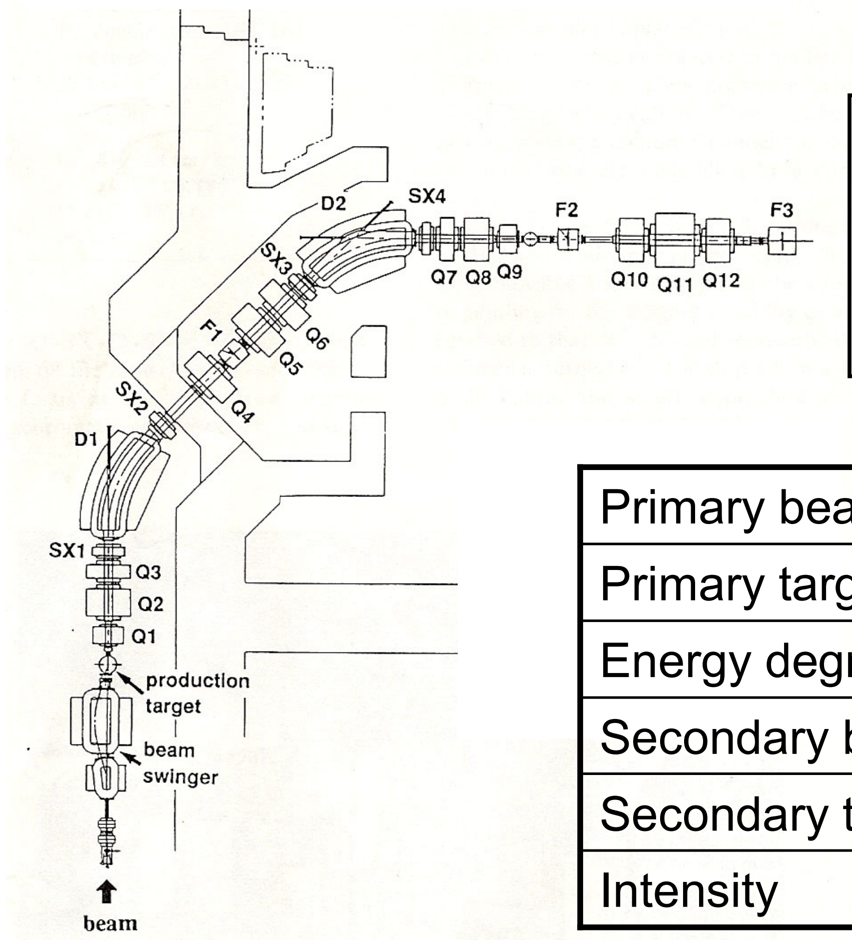


<u>Advantages:</u>

- Beam momentum is irrelevant to invariant mass;
  high resolution ~ 150 keV (in σ @ 1 MeV) can be attained.
- Kinematical focusing allows to use a detection system covering relatively small acceptance solid angles.
- Various reaction channels can be measured simultaneously.

Experimental Setup (1)

RIPS @ RIKEN accelerator facility

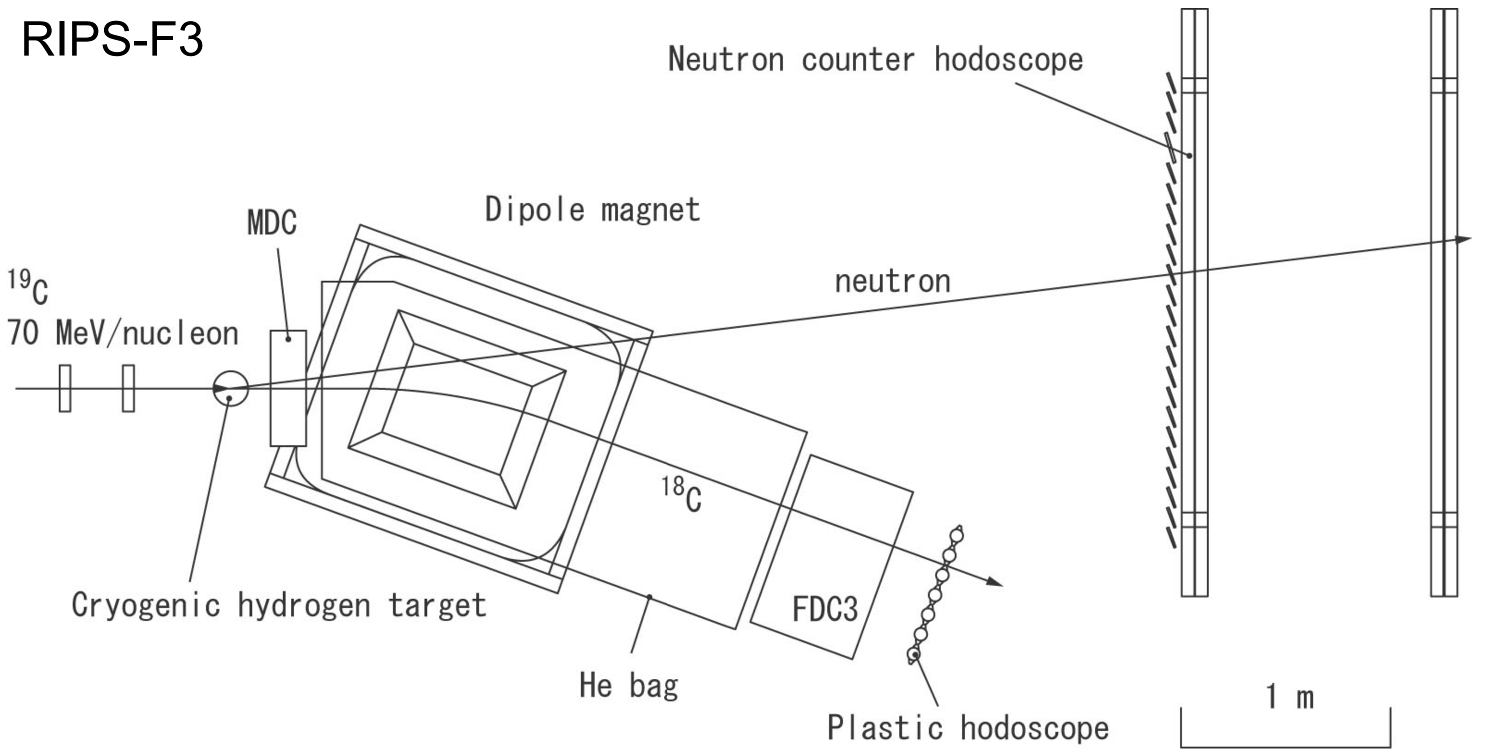


Experimental apparatus placed at F3

Primary beam	^{22}Ne@110 AMeV, 100 pnA
Primary target	Be : 6 mm
Energy degrader	Al : 3.03 mm
Secondary beam	^{19}C@70 AMeV
Secondary target	LH_2 : 120 mg/cm^2
Intensity	^{19}C : 260 cps

Experimental Setup (2)

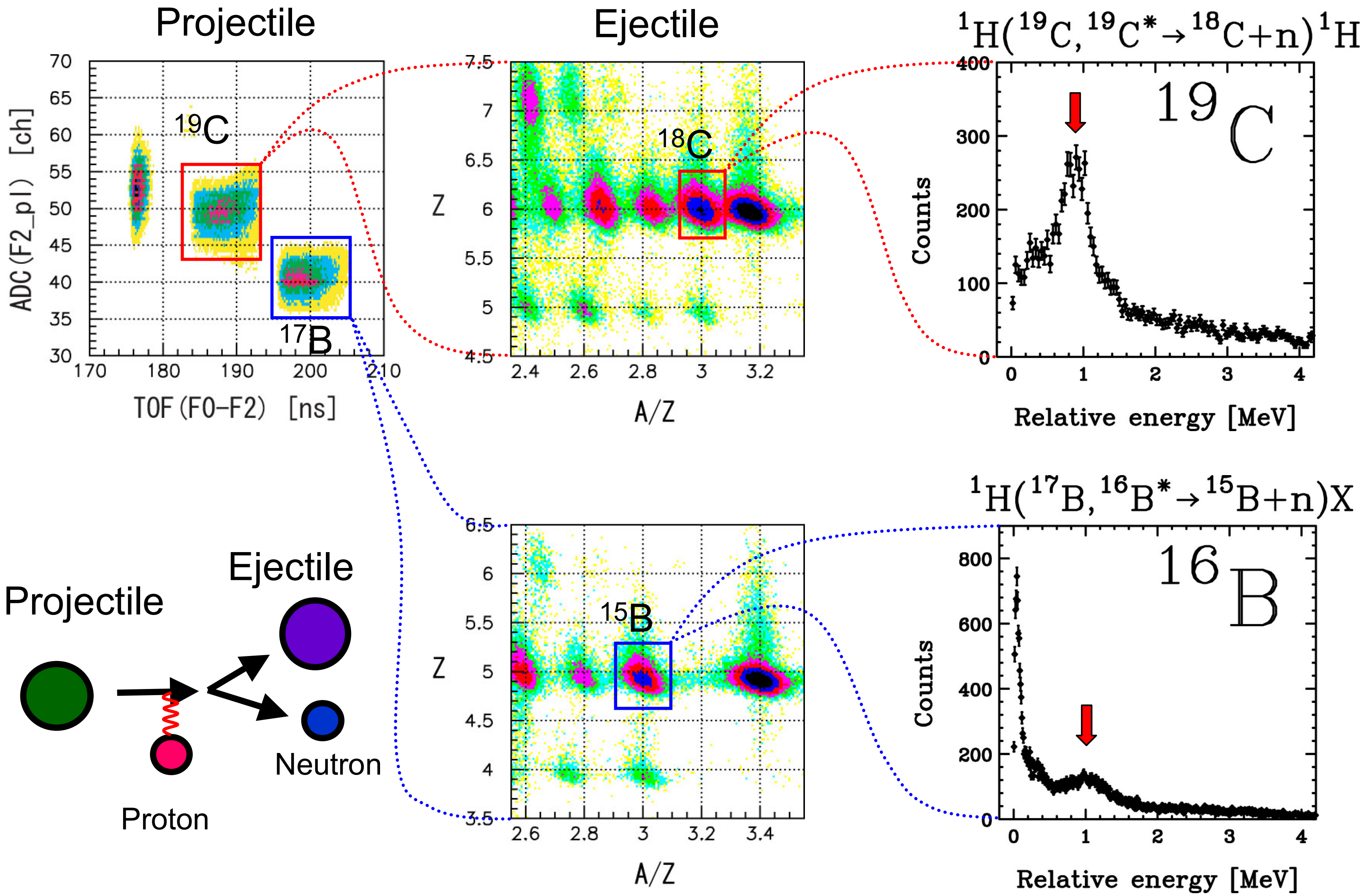
RIPS-F3



<u>Advantages in using cryogenic hydrogen target</u>

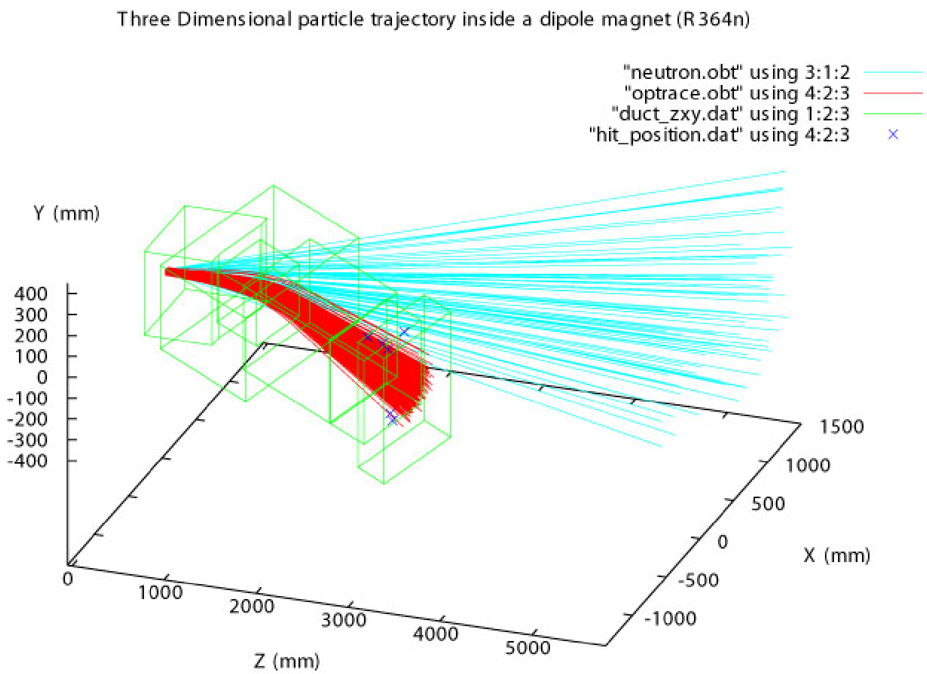
1. Coulomb multiple scattering effect is low => Good angular resolution
2. Number of target is large => High counting statistics
3. Inert & no contaminant component => Low background

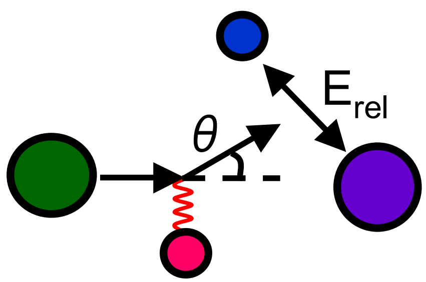
Particle Identification



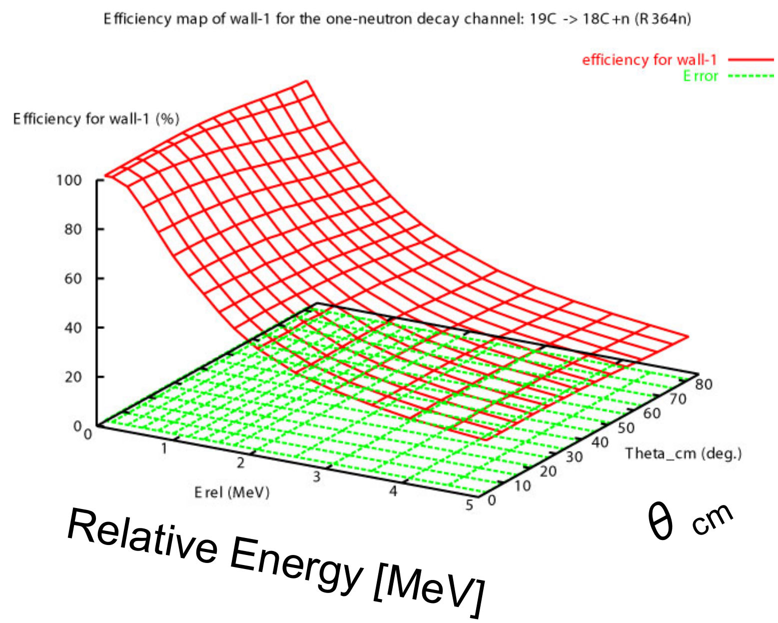
Acceptance Correction

Monte Carlo Simulation



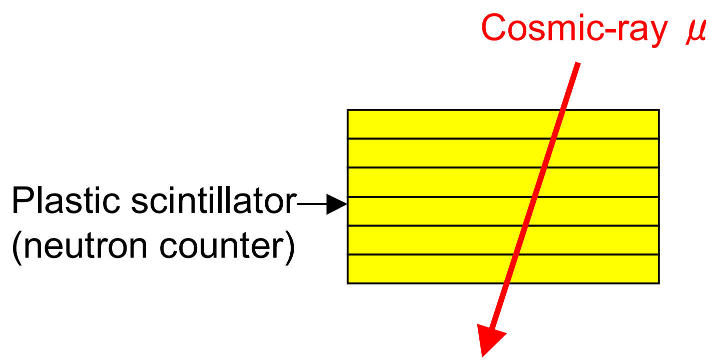


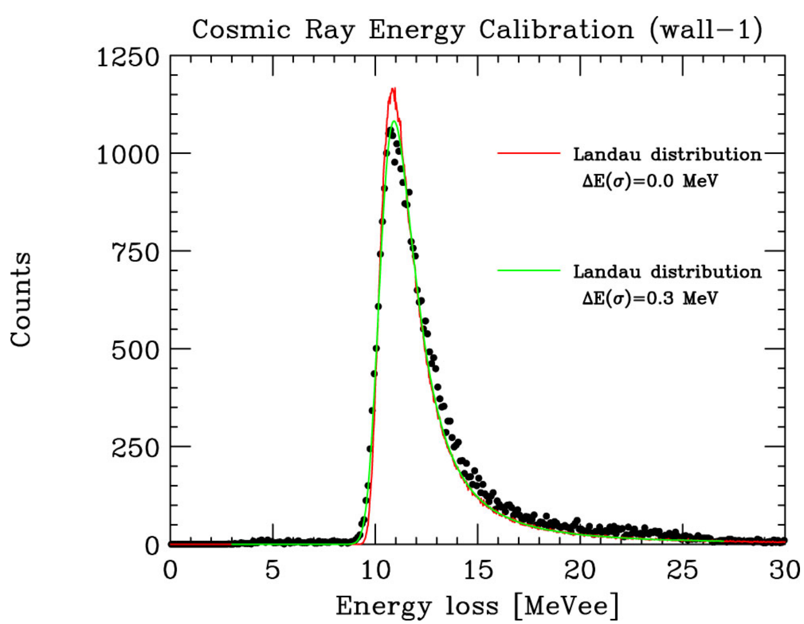
Acceptance Curve



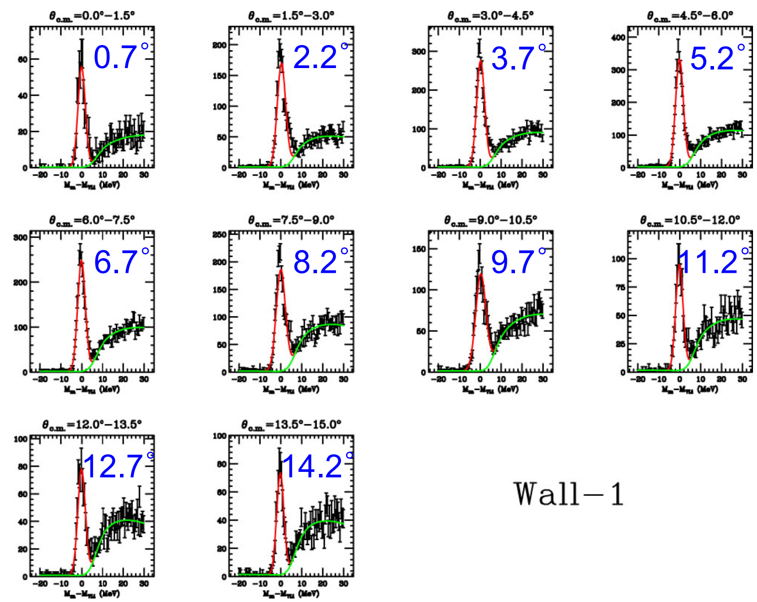
Intrinsic Neutron Detection Efficiency

- Pulse height calibration made with cosmic ray events.





- Efficiency calibration made with neutrons from the ^{7}Li(p,n) reaction.



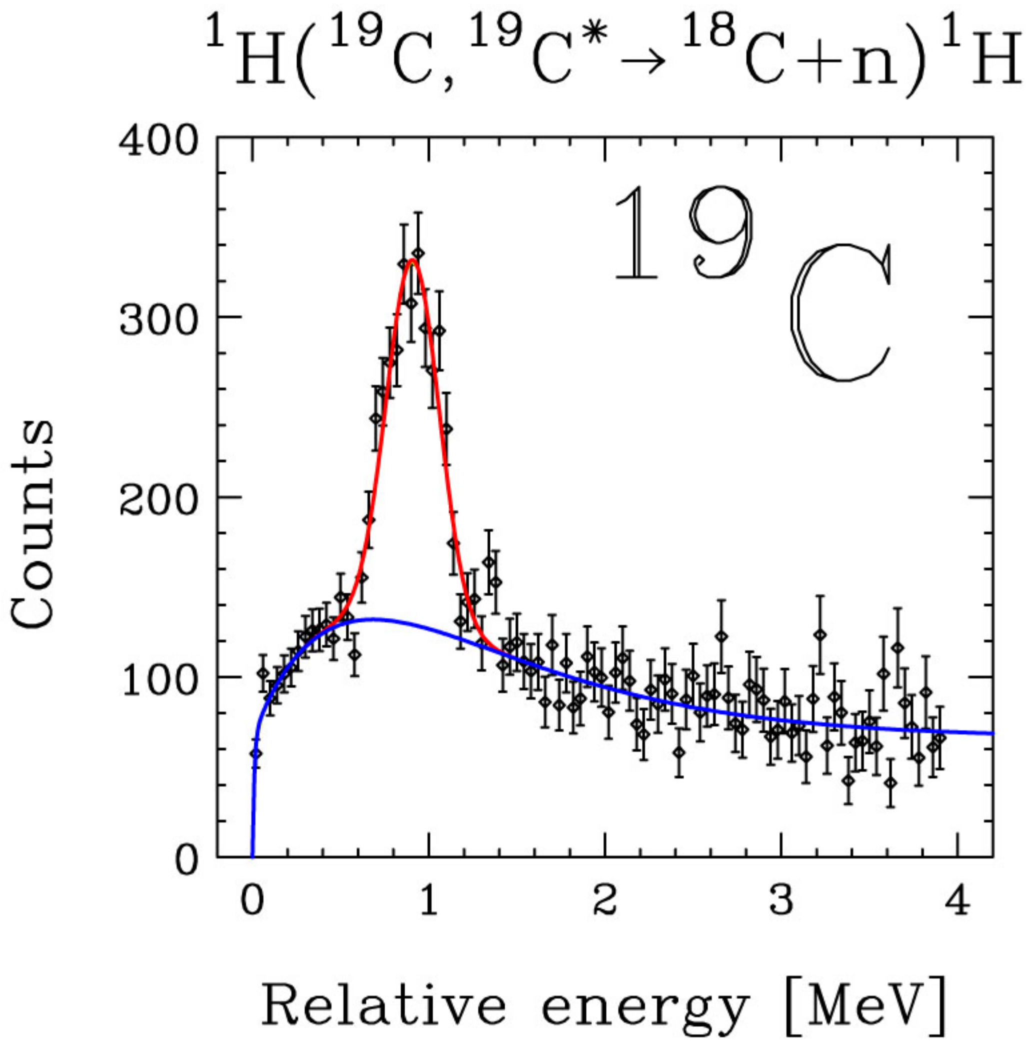
•(p,n) cross sections are normalized to values in Ref [T.N.Taddeucci PRC41(1990)2548].

•For a threshold setting of 4 MeVee. →

Wall-No	Efficiency
Wall-1	8.29±0.13%
Wall-2	8.12±0.13%
Wall-3	5.81±0.12%
Wall-4	6.09±0.13%
Total	28.31±0.25%

Results and Discussion

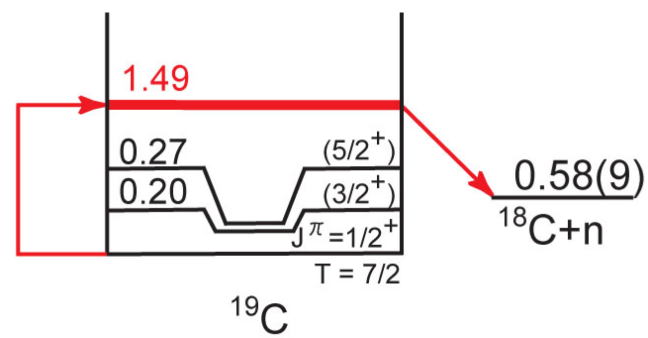
Invariant Mass Spectrum



E_{rel} =0.91±0.01 MeV
Γ_{obs}=0.35±0.01 MeV

$S_n(^{19}C)$=0.58±0.09 MeV

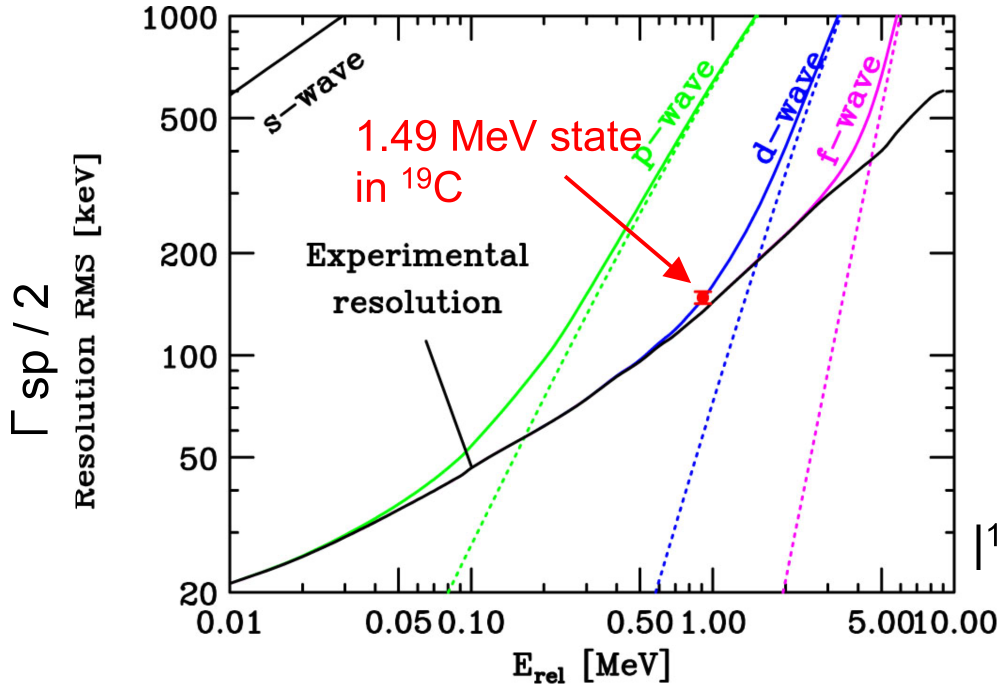
E_{ex}=1.49±0.09 MeV

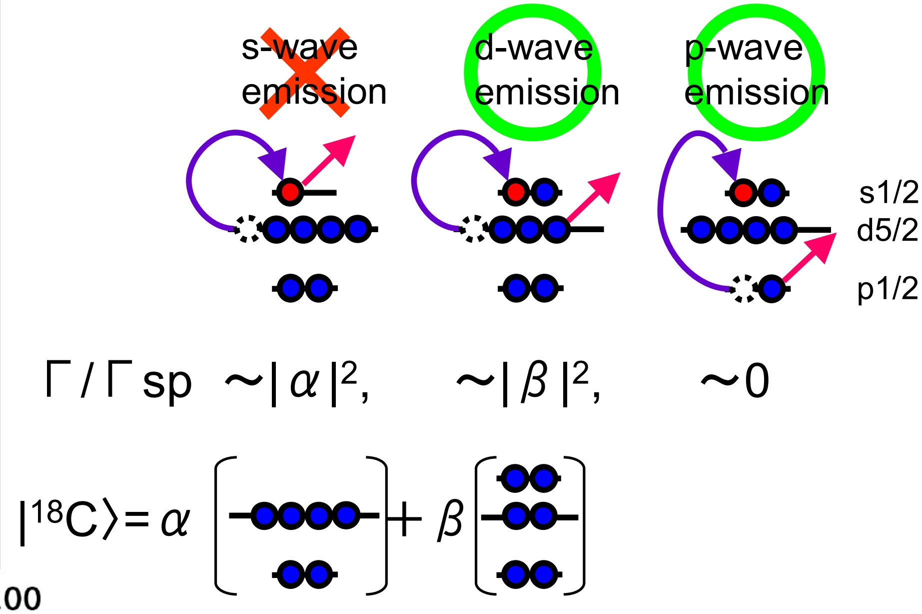


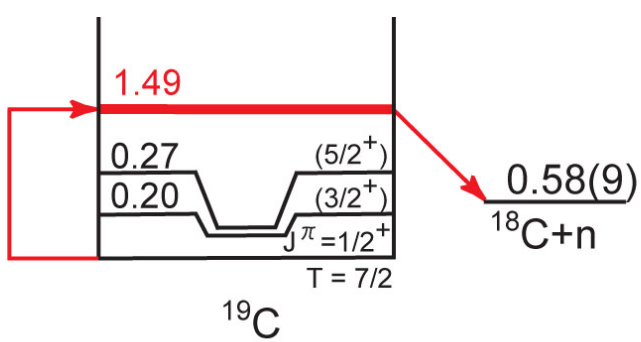
1. Width
2. Excitation energy
3. (Differential Cross Section)

Single Particle Estimate of the Width Γ_{sp}

Nuclear Structure Vol.1 p439
by Aage Bohr, Ben R. Mottelson



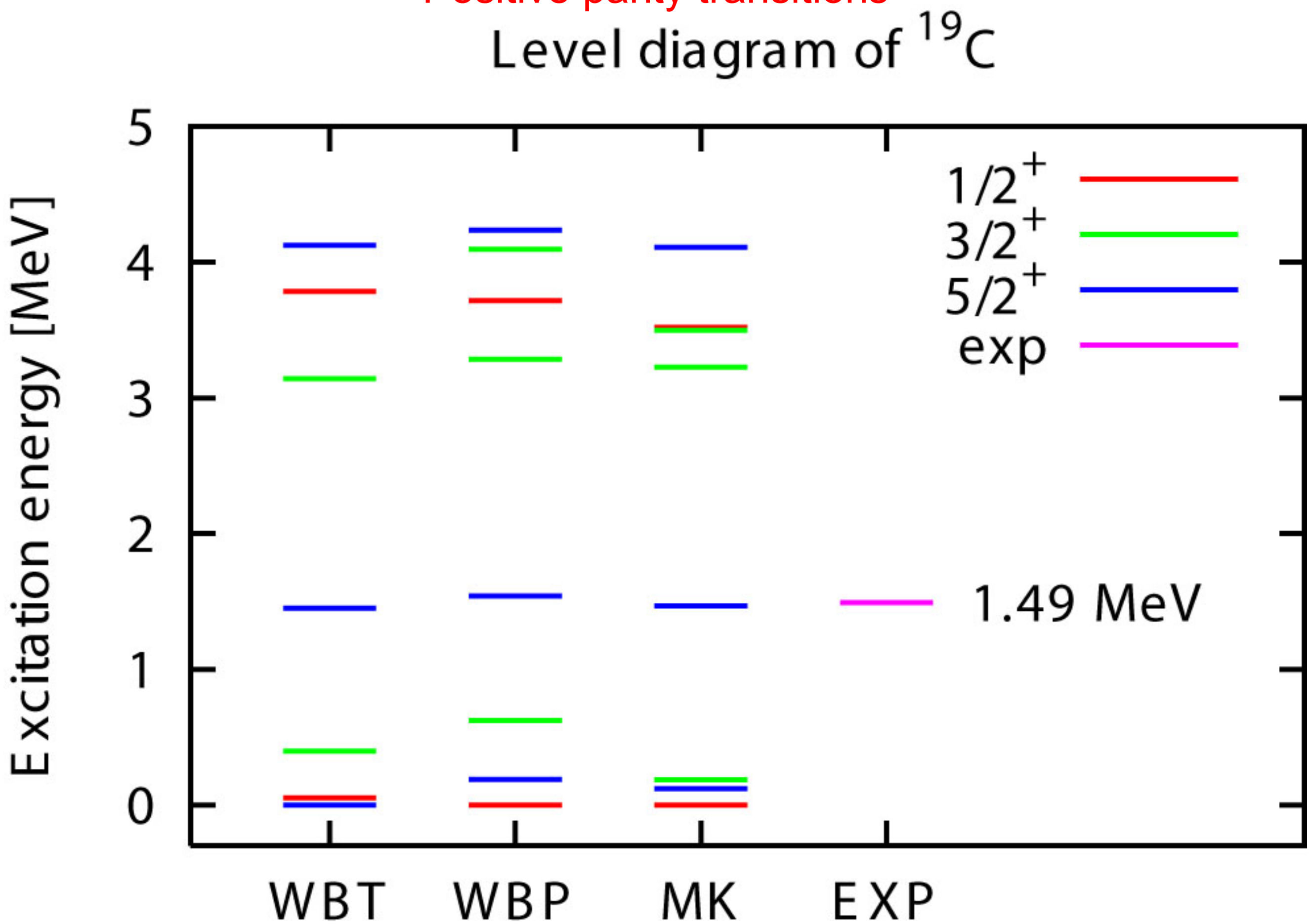




- The decay occurs either by d-wave or p-wave neutron emission.
- No limitation on parity from the width.

Energy Level Diagram (1)

Positive parity transitions



Model space: psd

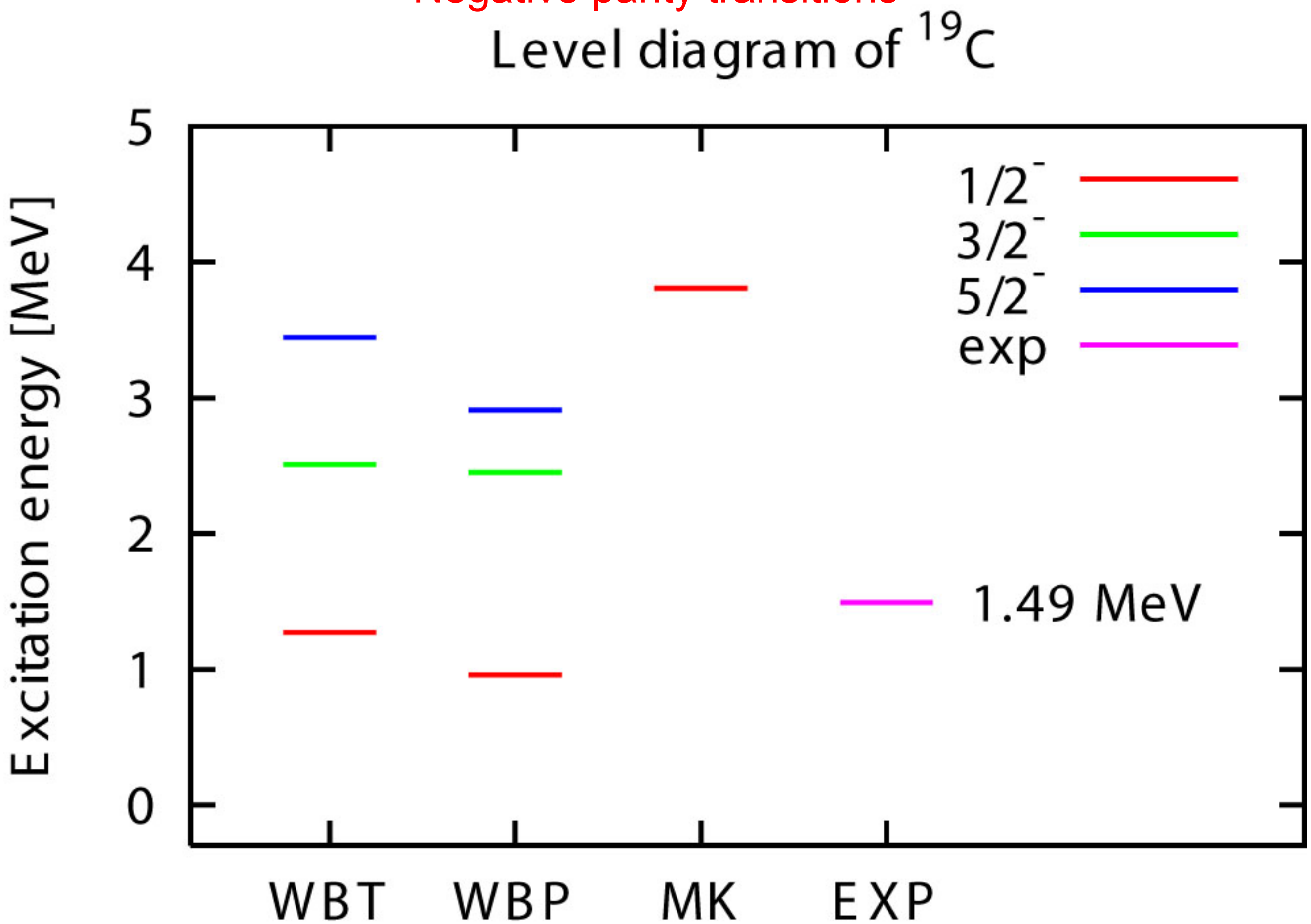
Shell model interaction:

WBT,WBP : E.K.Warburton and B.A.Brown, PRC46(1992)923.

MK : D.J.Millener and D.Kurath, NPA255(1975)315.

Energy Level Diagram (2)

Negative parity transitions



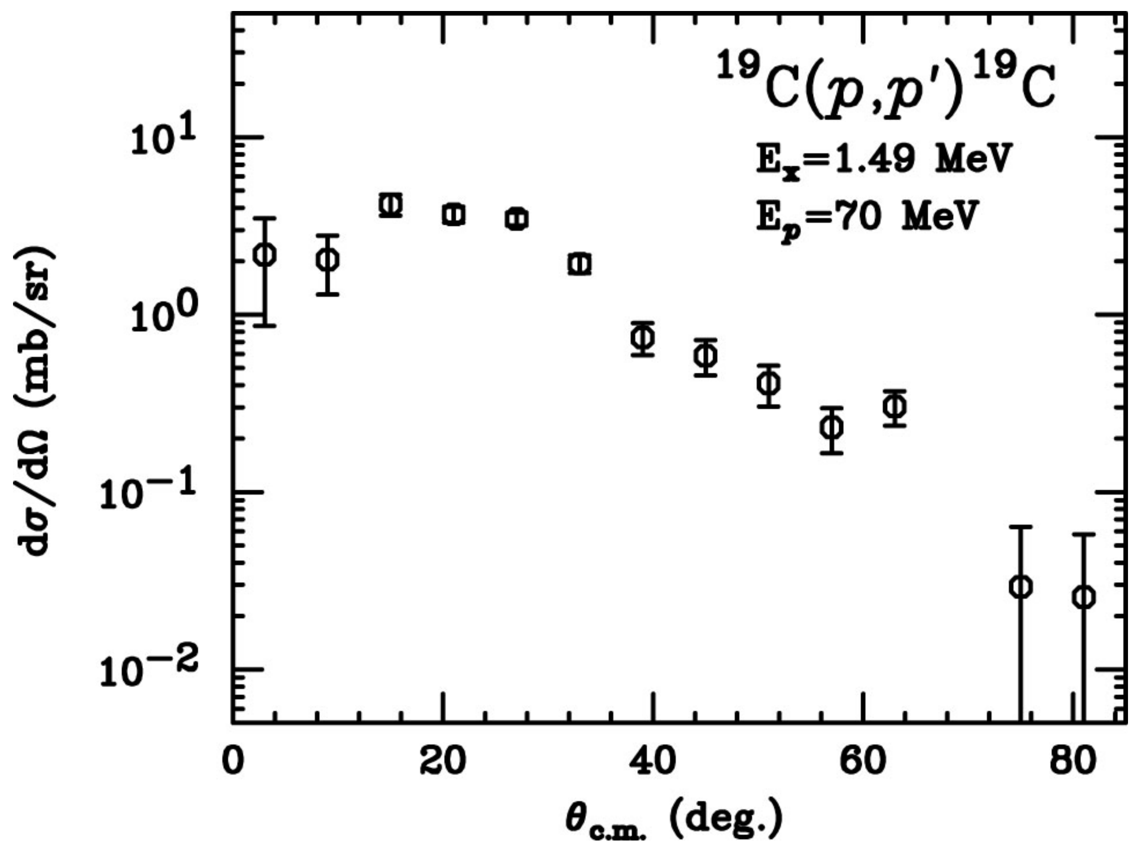
Model space: psd

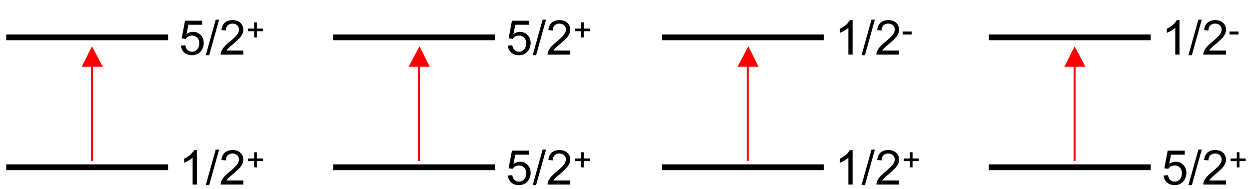
Shell model interaction:

WBT,WBP : E.K.Warburton and B.A.Brown, PRC46(1992)923.

MK : D.J.Millener and D.Kurath, NPA255(1975)315.

Differential Cross Section





Summary

- We have measured the $^{19}C(p,p')$ reaction at E_p=70 MeV by applying the invariant mass method in inverse kinematics.
- In an invariant mass spectrum, a previously unknown peak was identified at E_x=1.49 MeV in ^{19}C.
- From the observed width (Γ =0.35 MeV), d or p-wave neutron emission was suggested for the decay of the peak.
- From comparison in excitation energy with shell model calculations, spin and parity of the state was suggested to be either $5/2^+$ or $1/2^-$.