Anomalously Hindered *E2* Strengths in ^{16,18}C

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Now available: Physical Review C 78, 014308 (2008)

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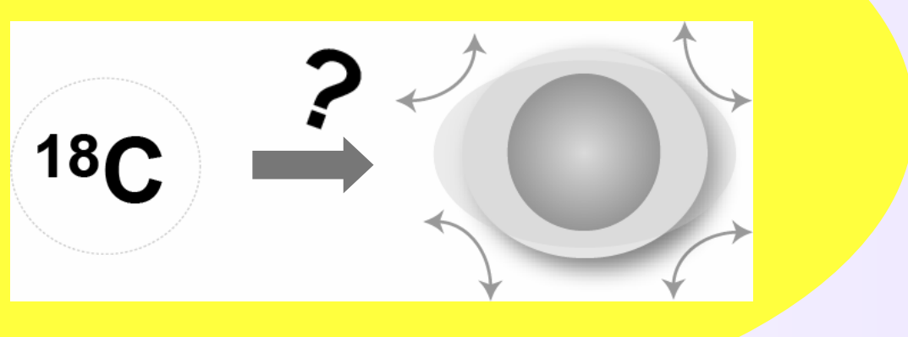
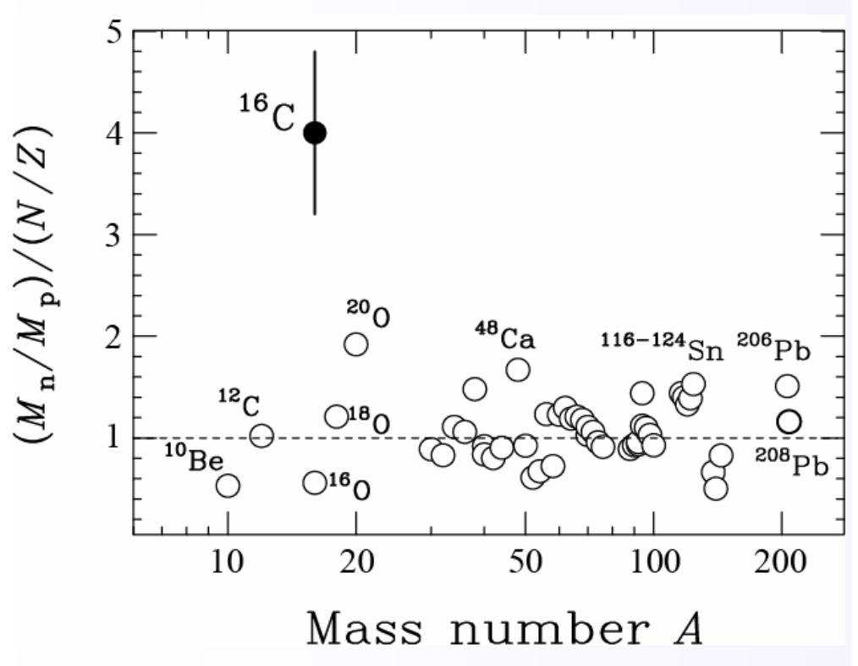
QUESTION:



Determine the *B(E2)*

Fig. 2



◎ Lifetime measurement of the 2_1^+ state in ^{16}C

➡**Anomalously hindered *E2* strength in ^{16}C** (as shown by ○ in Fig. 1)

N. Imai et al, PRL 92, 062501 (2004)

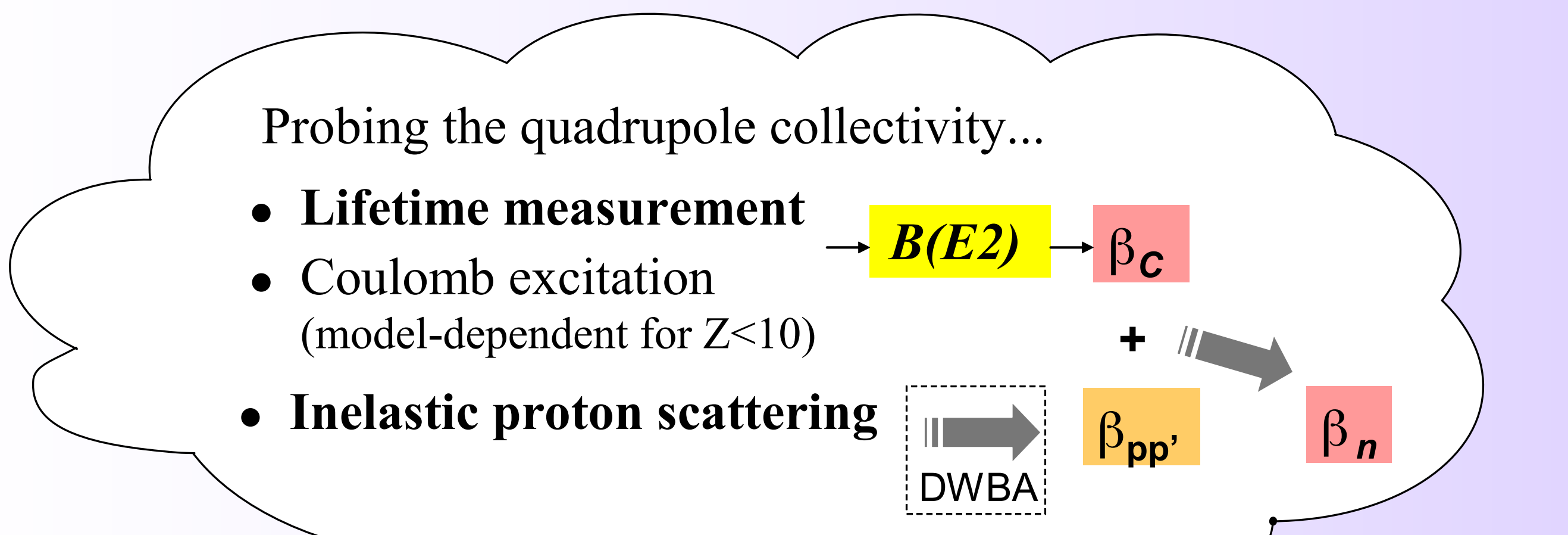
◎ Combined with the results from the inelastic proton scattering

➡**Neutron-dominant quadrupole collectivity in ^{16}C** (see Fig. 2)

H. J. Ong et al, PRC 73, 024610 (2006)

See also

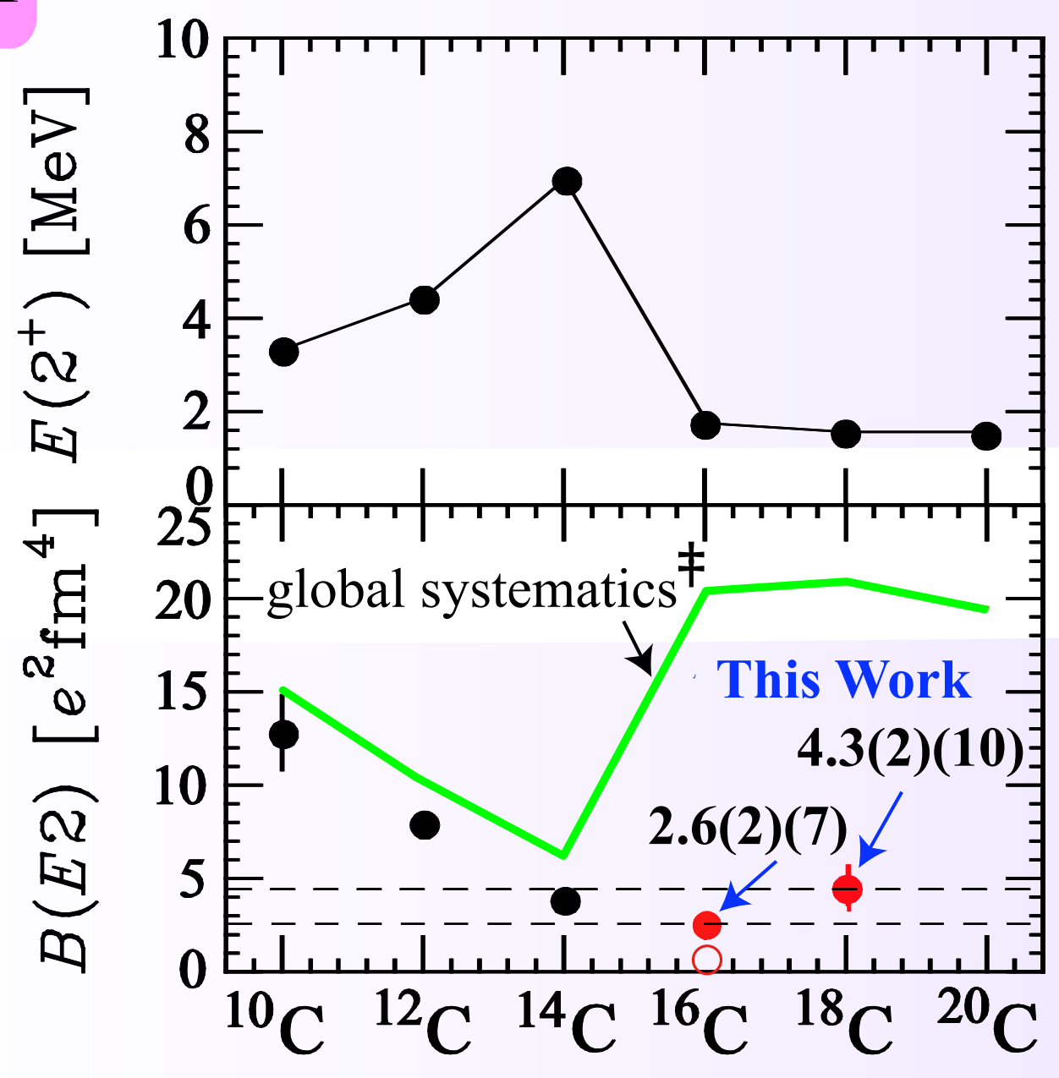
Z. Elekes et al, PLB 586, 34 (2004)



Probing the quadrupole collectivity...

- **Lifetime measurement** → ***B(E2)*** → β_C
- Coulomb excitation (model-dependent for Z<10) +
- **Inelastic proton scattering** → DWBA → $\beta_{pp'}$ → β_n

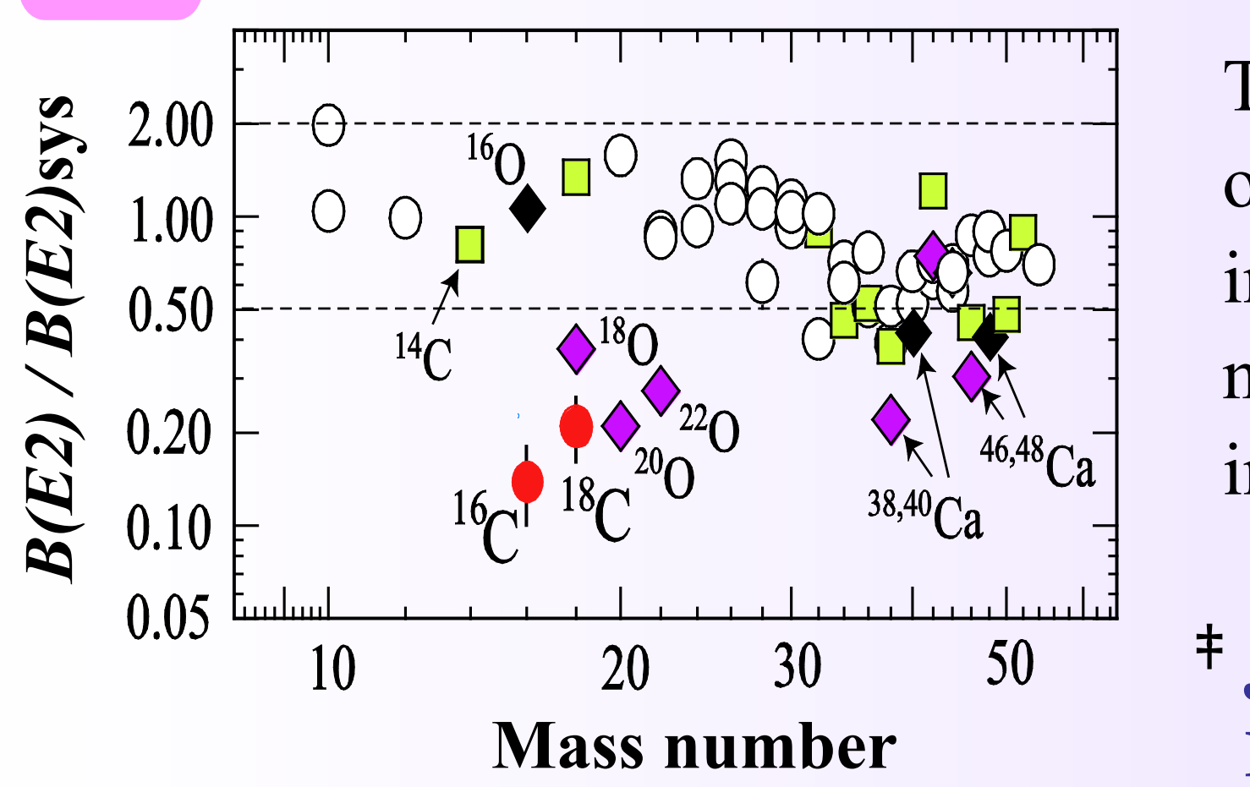
Fig. 1



‡ **S. Raman et al, ADNDT 78, 1 (2001)**
○ **N. Imai et al, PRL 92, 062501 (2004)**

While the significant drops in $E(2_1^+)$ from ^{14}C to ^{16}C and ^{18}C seem to suggest enhanced quadrupole collectivity, we show that
(i) the protons hardly contribute to the *E2* strength, and
(ii) the excitations are (or very likely for the ^{18}C case) a neutron-dominant one(s).

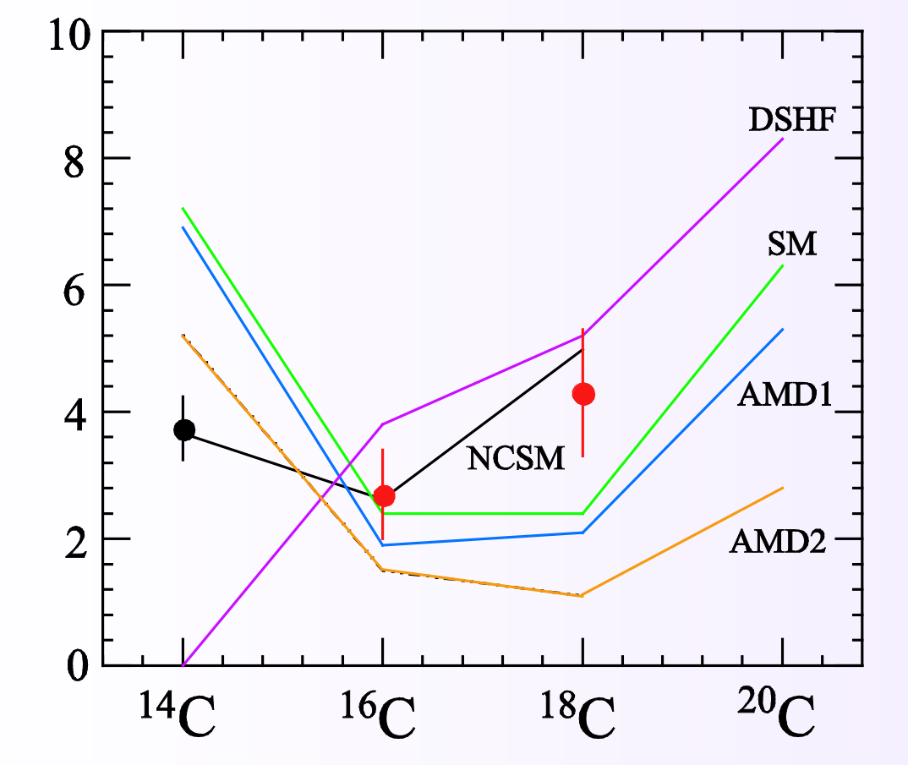
Fig. 7



The low $E(2_1^+)$ and small *B(E2)* value observed for ^{18}C, a trend observed also in ^{16}C and ^{20}O ‡ , indicate a possible neutron-dominant quadrupole collectivity in ^{18}C.

‡ **J. K. Jewell et al, PLB 454, 181 (1999); E. Khan et al, PLB 490, 45 (2000)**

Fig. 6



SM	**R. Fujimoto, Ph.D Thesis, UT (2003)**
DSHF	**H. Sagawa et al, PRC 70, 054316 (2004)**
AMD1	**Y. Kanada-En'yo, PRC 71, 014310 (2005)**
AMD2	**G. Thiamova et al, EPJA 22, 461 (2004)**
NCSM	**S. Fujii et al, PLB 650, 9 (2007)**

Comparison with microscopic theoretical predictions:

◎ Shell Model predicts proton-closed shell in ^{16,18}C

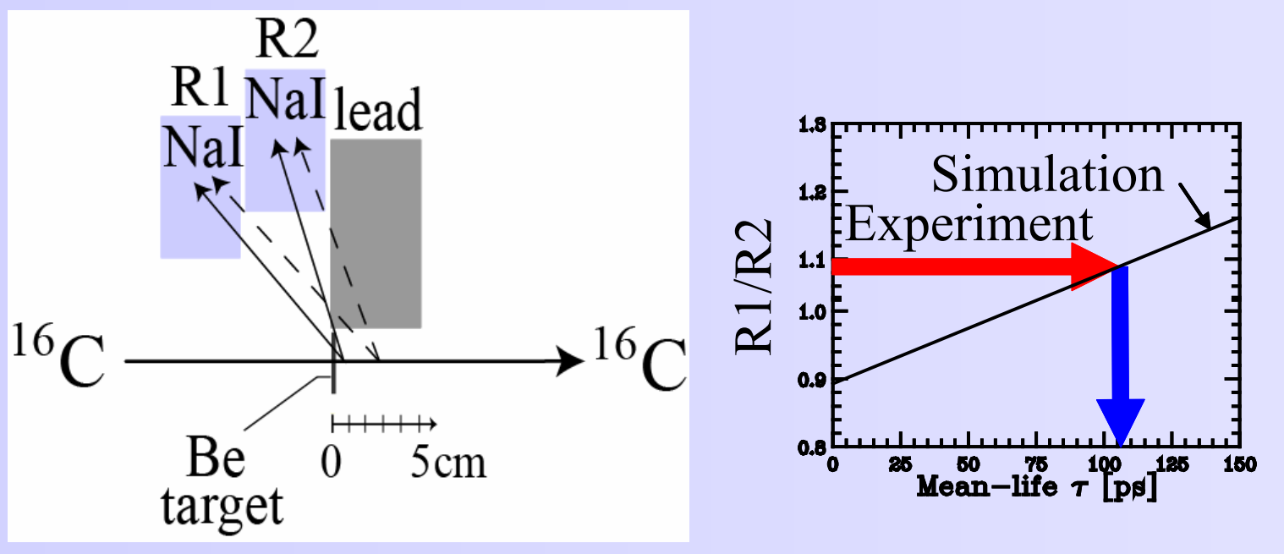
◎ AMD predicts opposite deformations in ^{16,18}C

◎ "No-core" Shell Model reproduces *B(E2)* values for the neutron-rich ^{14,16,18}C quite well, when a small neutron effective charge $e_n = 0.164e$ is assumed.

Both SM and AMD look promising in explaining the small *B(E2)* values; but which picture is correct? More experimental data are necessary. For the immediate future, it will be interesting to see whether the *B(E2)* value for ^{20}C increases as predicted.

Recoil Shadow Method

N. Imai et al, PRL 92, 062501 (2004)

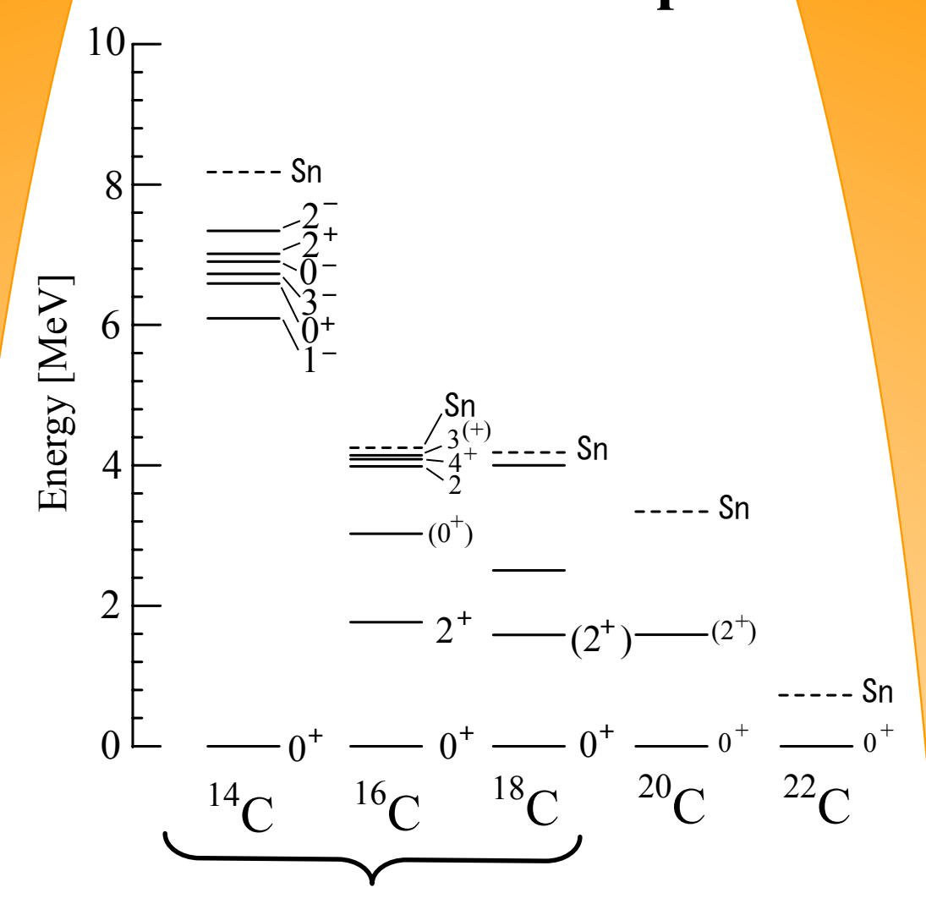


◎ 32 NaI(Tl) detectors were used.
◎ Lifetime was determined by comparing the measured R1/R2(exp) with the simulated R1/R2(sim;τ), for which an angular distribution of the γ rays was assumed in the simulation.

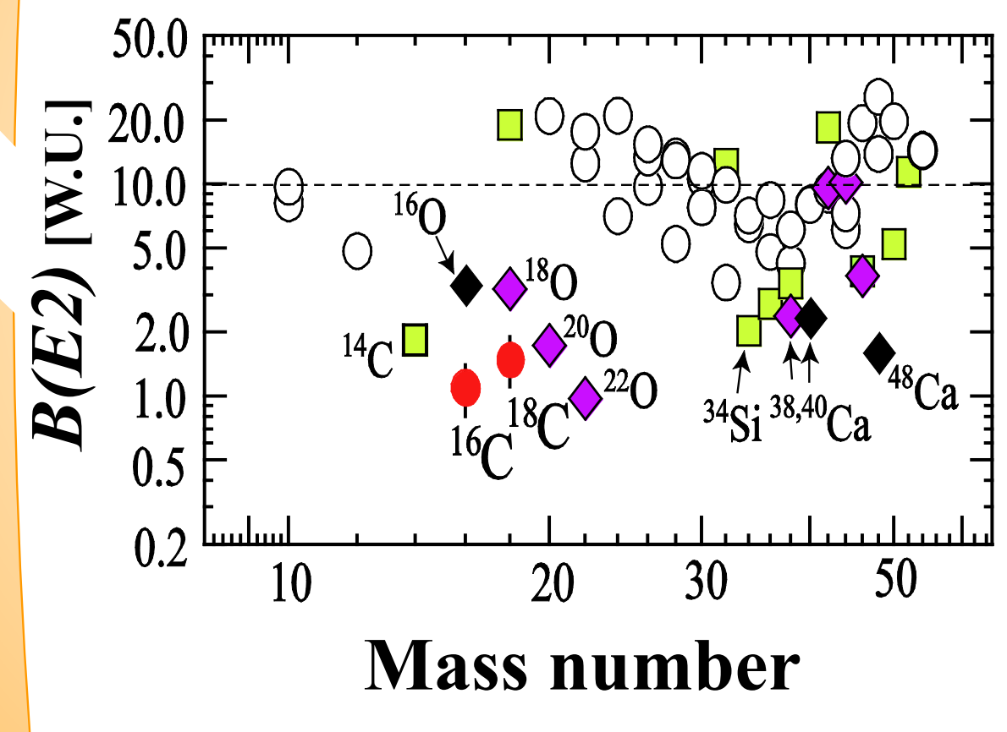
Method & Experiment

Motivation

Level schemes of even-even C isotopes



+



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Possible proton-shell closure in ^{14,16,18}C

Data Reduction & Results

Discussion

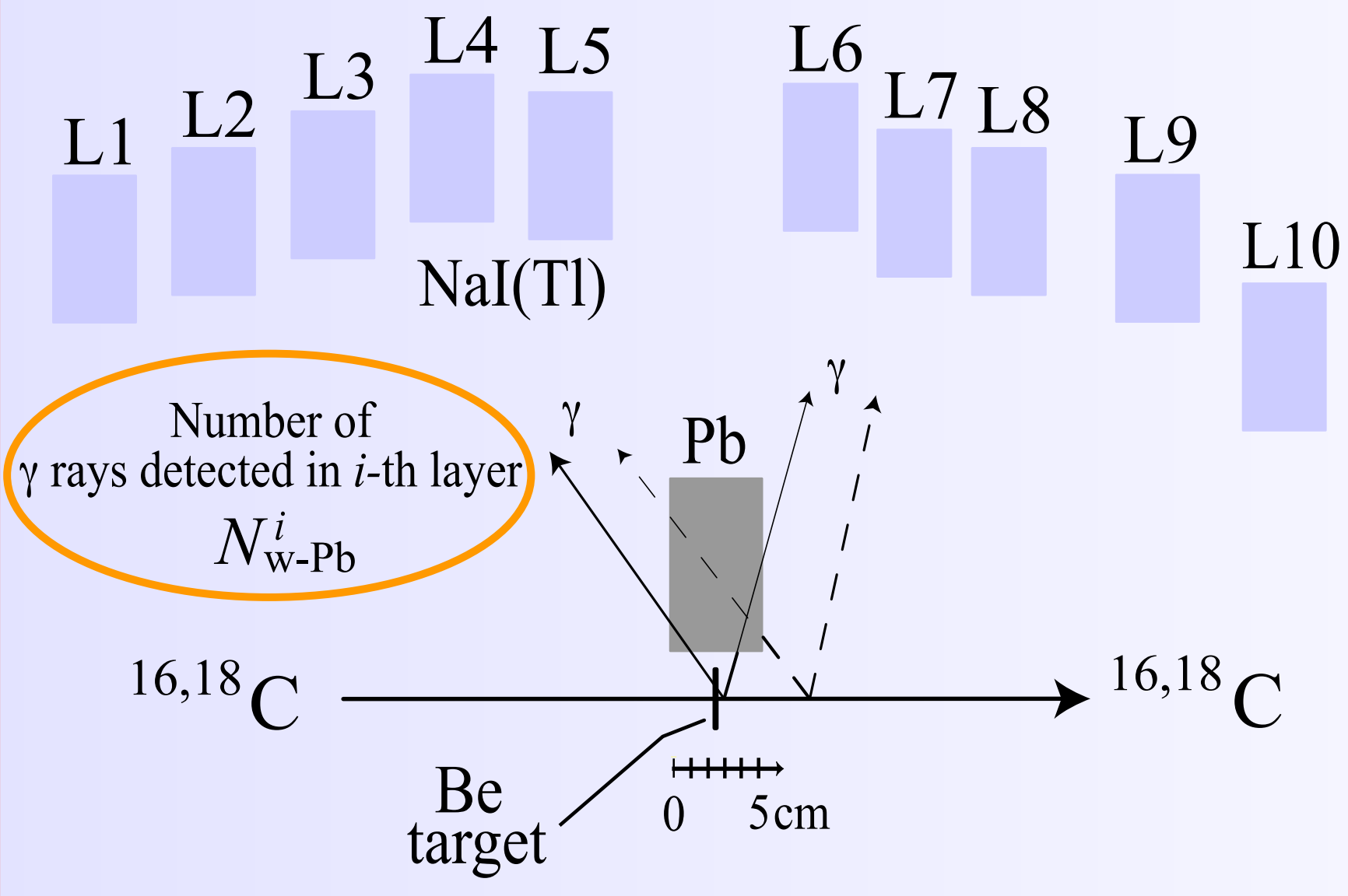
RESULTS

Small *B(E2)* values!!
(See Fig.1)

	τ (2_1^+) [ps]	*B(E2)* [e²fm⁴]	*B(E2)* [W.u.]
^{18}C	**18.9(9)(44)**	**4.3(2)(10)**	**1.5(1)(4)**
^{16}C^a	**17.7(16)(46)**	**2.7(2)(7)**	**1.1(1)(3)**
^{16}C^b	**19.6(30)(45)**	**2.4(4)(6)**	**1.0(2)(2)**
^{16}C^c	**34(14)(9)**	**1.4(6)(4)**	**0.6(2)(2)**
^{16}C^d	77(14)(19)	0.63(11)(15)	0.26(5)(6)
^{16}C^e	11.7(20)	4.1(7)	1.7(3)

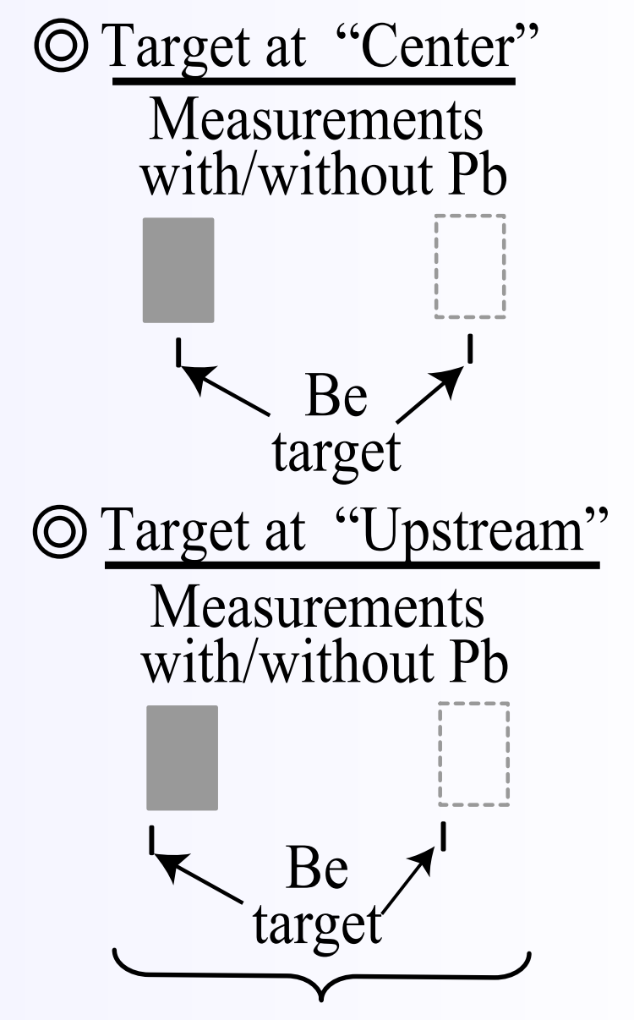
a: inelastic channel @ 72 MeV/nucleon
b: breakup channel @ 79 MeV/nucleon
c: inelastic channel @ 40 MeV/nucleon
d: inelastic channel @ 40 MeV/nucleon; previous result *
* **N. Imai et al, PRL 92, 062501 (2004)**
e: LBL data; **M. Wieldeking et al, PRL 100, 152501 (2008)**

Upgraded Recoil Shadow Method



◎ 130 NaI(Tl) detectors were used to compensate for the lower beam intensity.
◎ Lifetime was determined by comparing the measured D^i_ε(exp) with the simulated D^i_ε(sim;τ), which is free of uncertainty in the angular distribution of γ rays.

Variety of measurements



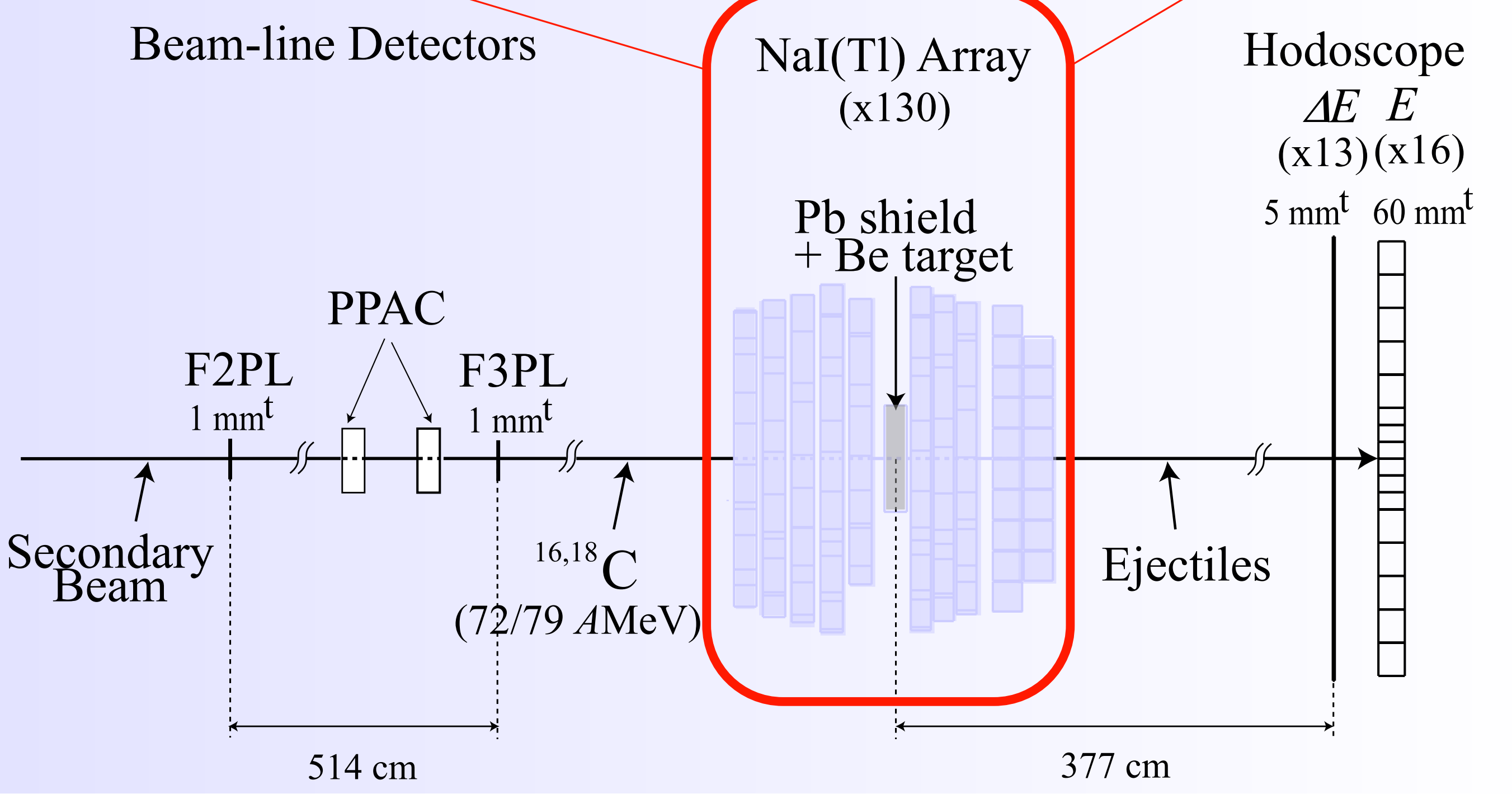
◎ Target at "Center"
Measurements with/without Pb
Be target

◎ Target at "Upstream"
Measurements with/without Pb
Be target

Deficiency:

$D^i_\varepsilon(\mathrm{exp}) \equiv N^i_{\text{w-Pb}}/N^i_{\text{wo-Pb}}$

Experimental Setup @ RIPS (RIKEN)



Determination of mean lifetime

To determine the mean lifetime, we performed Monte Carlo simulations using the GEANT3
(1) to determine D^i_ε(sim;τ), and
(2) to generate response functions for use in fitting to deduce D^i_ε(exp)

Procedures for simulations:

Step 1 Beam info
- position on target, θ
- energy

\+ Scattered particle info
- scattered θ
- energy

➡ **Ejectiles (^{18}C or ^{16}C)**

Step 2 Generation and detection of γ rays
- generated isotropically in CM frame
- Lorentz boost
- "detected" by NaI(Tl)

Fig. 3

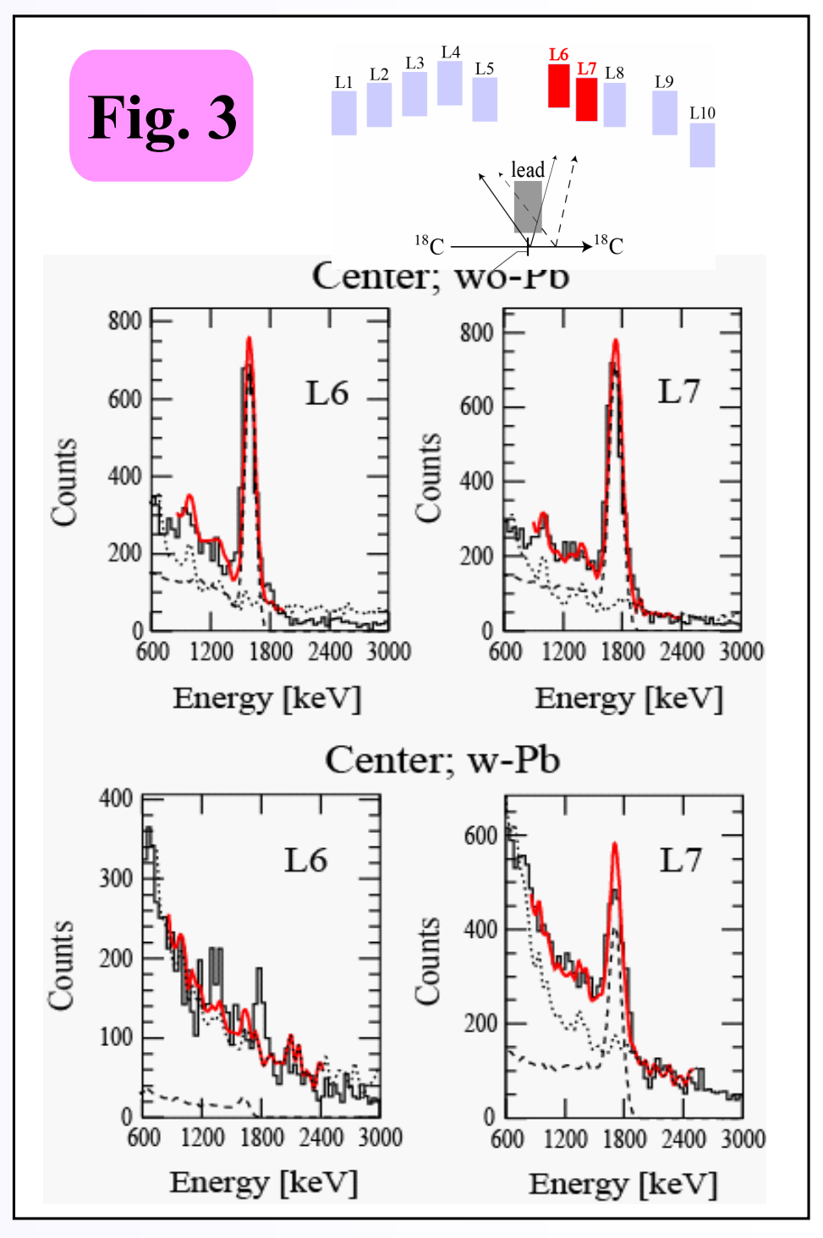
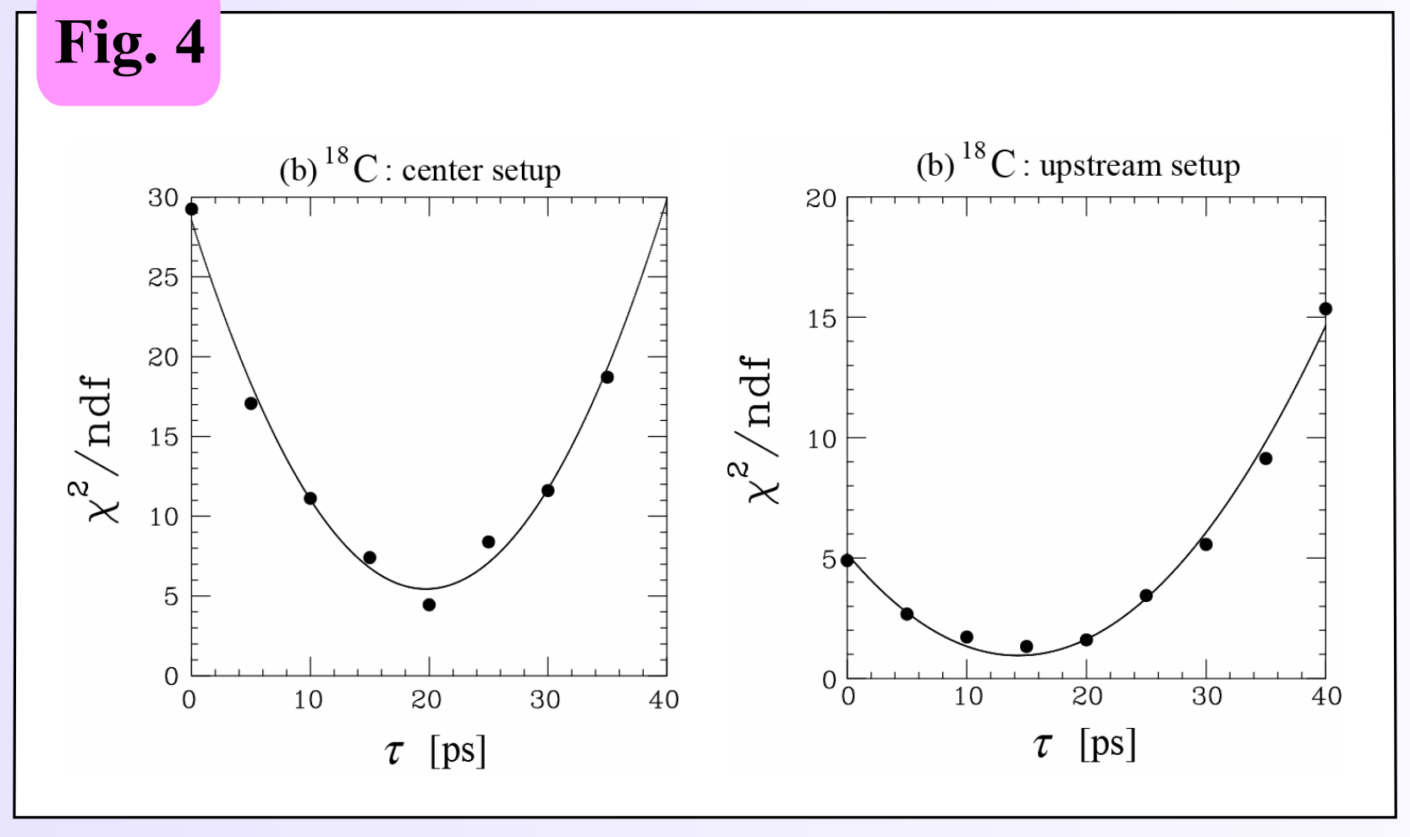
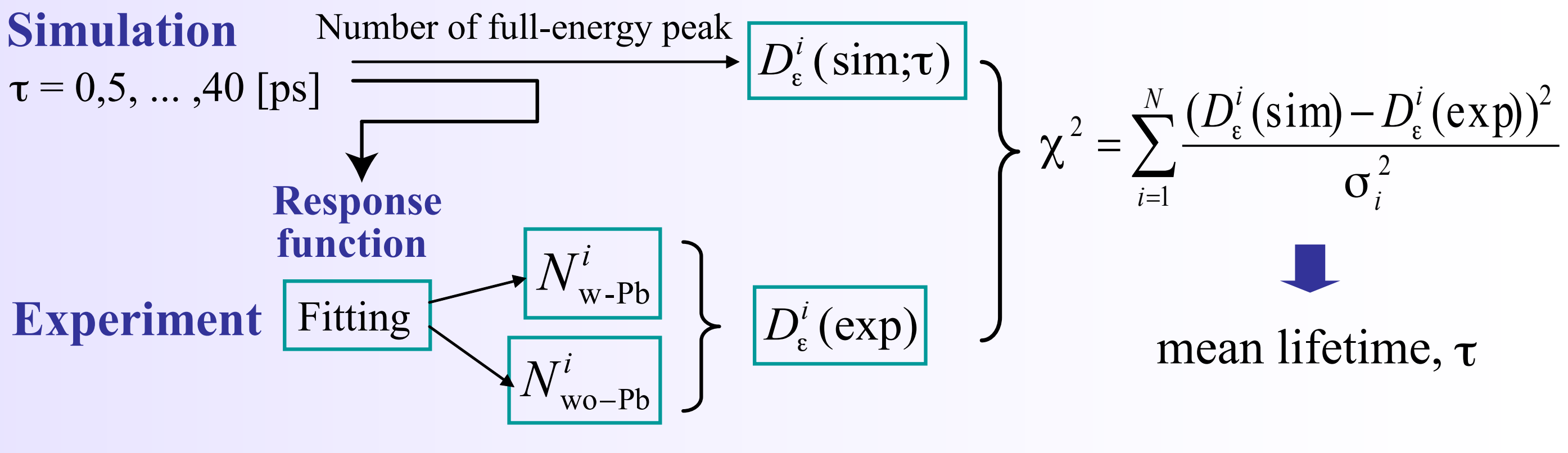


Fig. 4





Simulation τ = 0,5, ... ,40 [ps] — Number of full-energy peak → D^i_ε(sim;τ)

Response function

Experiment Fitting → $N^i_{\text{w-Pb}}$, $N^i_{\text{wo-Pb}}$ → D^i_ε(exp)

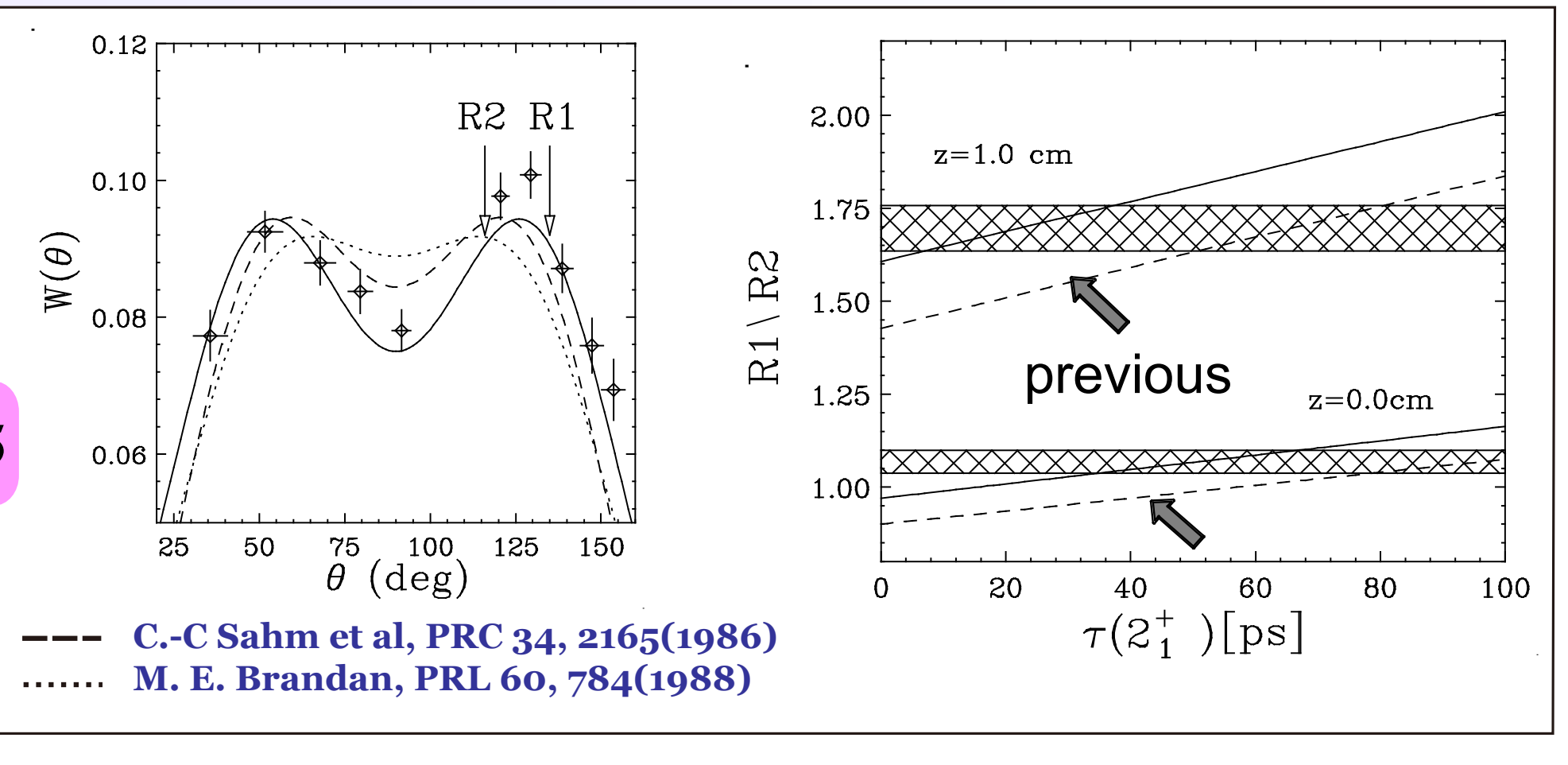
$$\chi^2=\sum_{i=1}^{N}\frac{(D^i_\varepsilon(\mathrm{sim})-D^i_\varepsilon(\mathrm{exp}))^2}{\sigma_i^2}$$

⬇

mean lifetime, τ

Besides ^{18}C, the mean lifetime $\tau(2_1^+)$ for ^{16}C was also remeasured with two reaction channels. Moreover, angular distribution of γ rays, which was not determined in the previous work (PRL 92, 062501(2004)), was also measured and incorporated into an improved reanalysis of the previous data.
(See Fig.5)

Fig. 5



– – – **C.-C Sahm et al, PRC 34, 2165(1986)**
…… **M. E. Brandan, PRL 60, 784(1988)**