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

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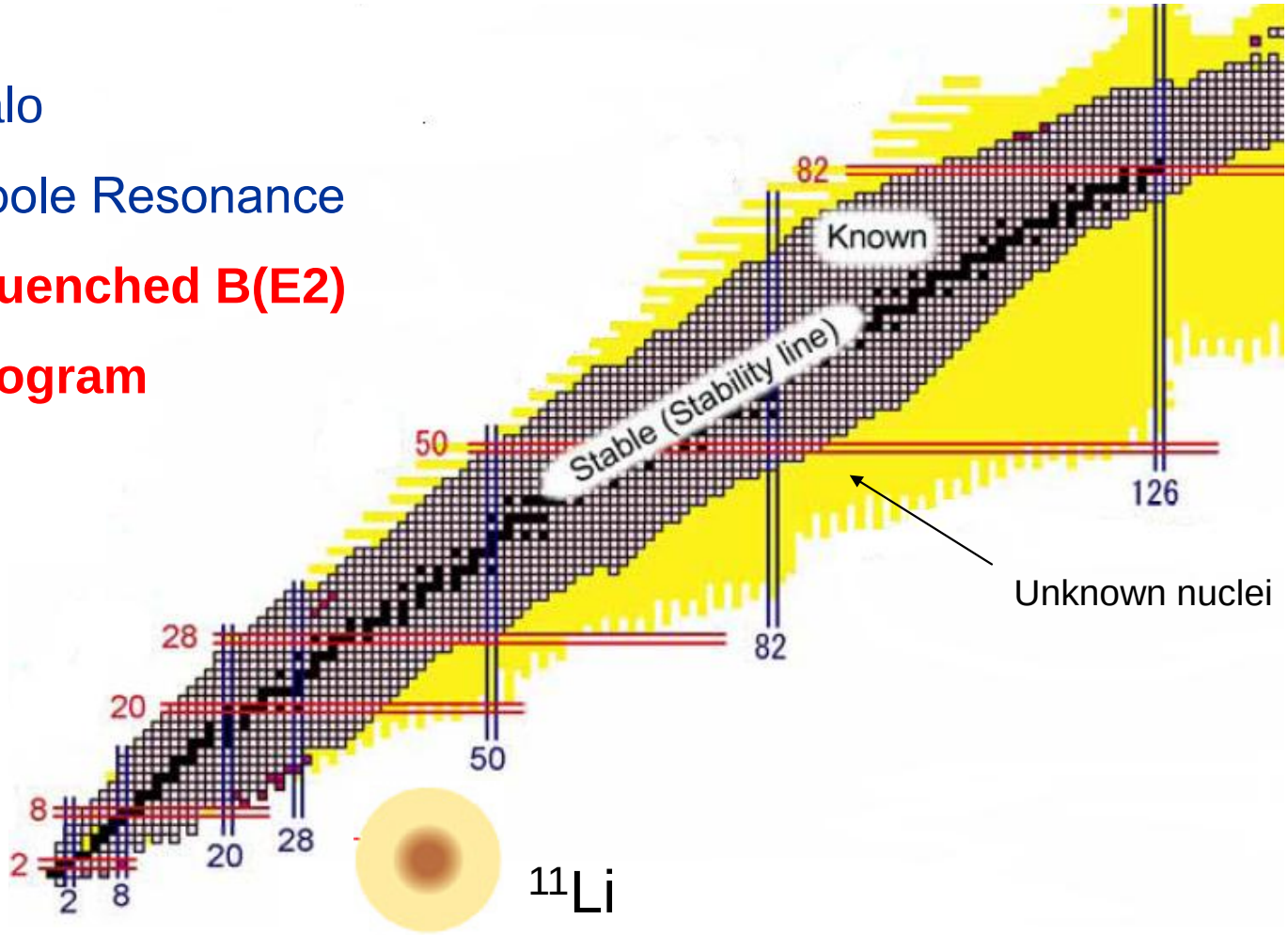
“Decoupled fluids”

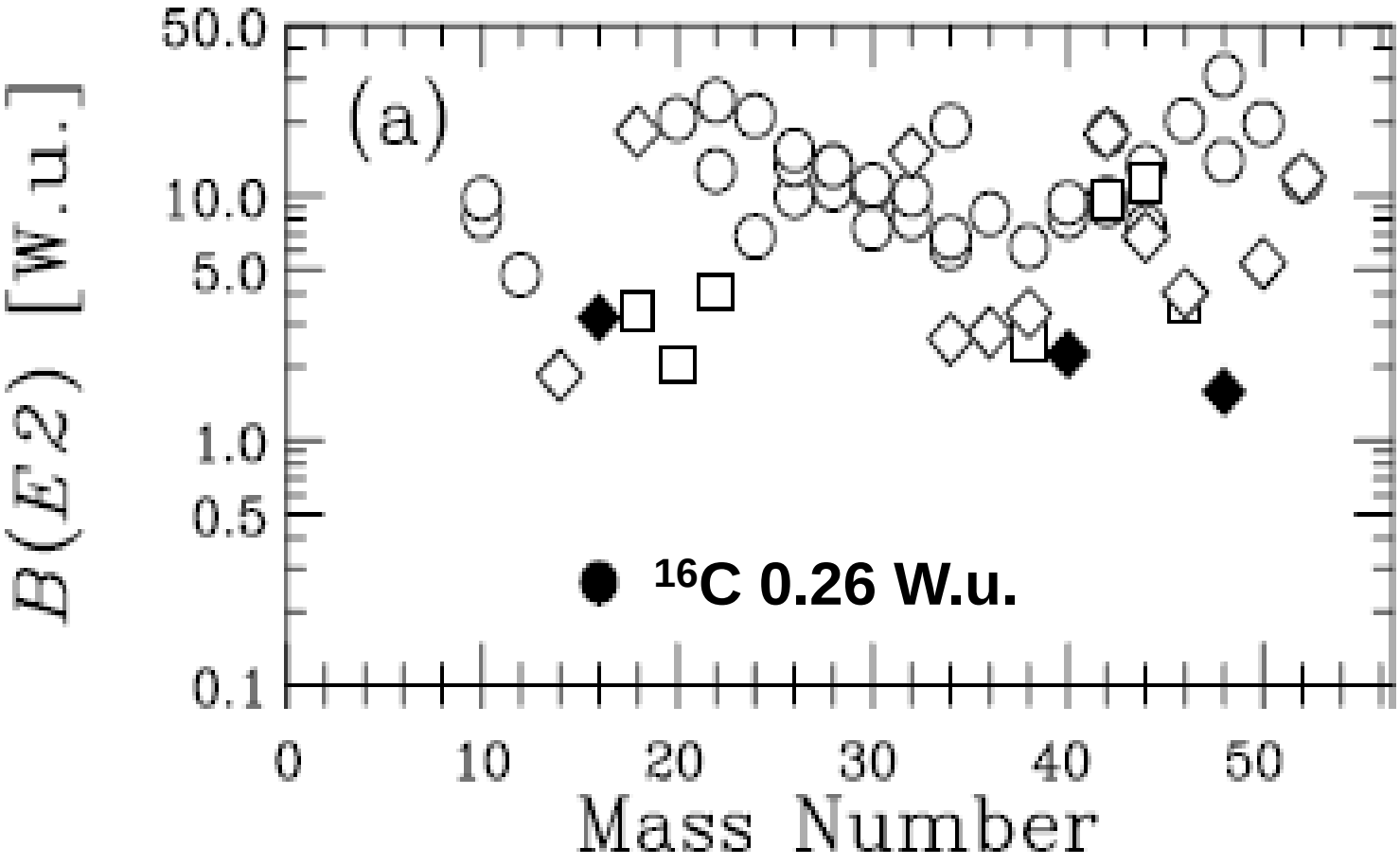
- Neutron Halo
- “Pygmy” Dipole Resonance
- **^{16}C, ^{17}B – quenched B(E2)**

  RIKEN Program



^{16}C : Anomalous Hindered B(E2, $2^+ \rightarrow 0^+$)

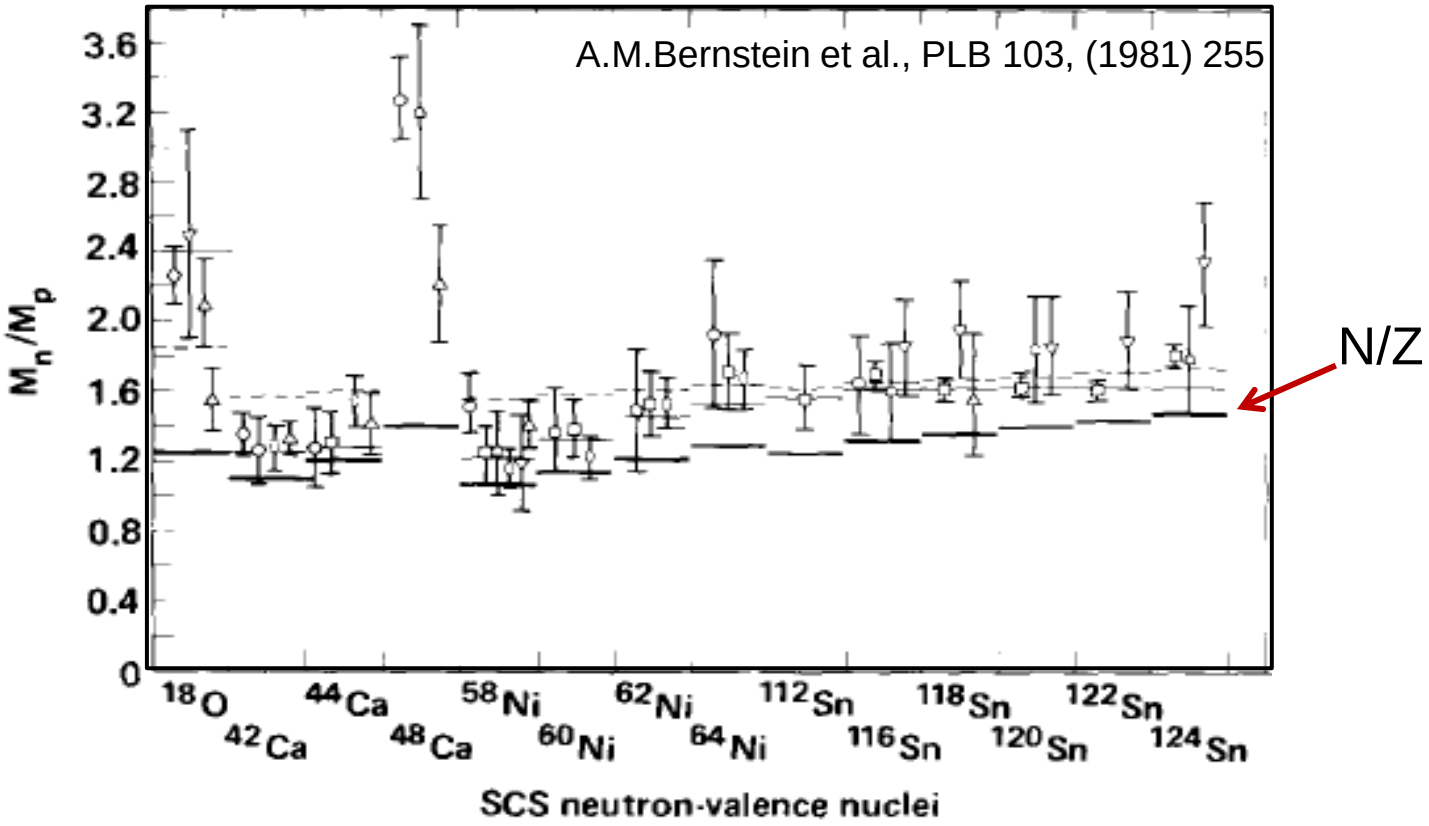
N. Imai et. al., Phys. Rev. Lett. **92**, 062501 (2004)



Proton and Neutron Transition Strengths (M_n/M_p)

Collective model → $M_n/M_p \sim N/Z$

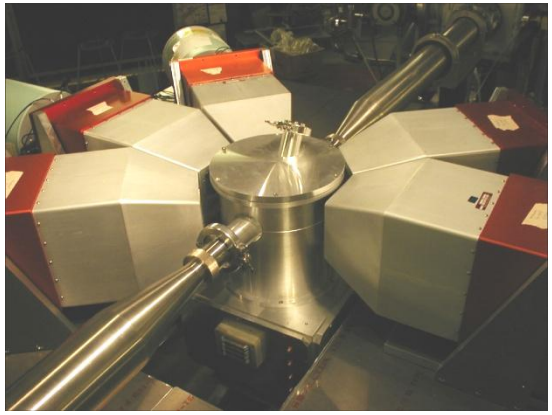
Deviations from ~ N/Z may signal differences in p and n distributions



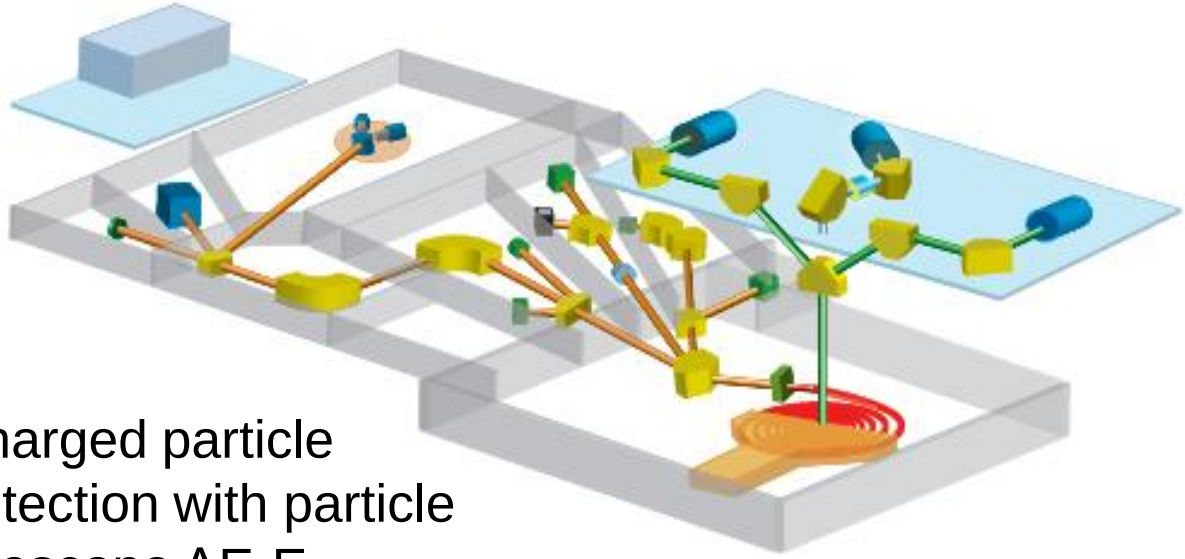
^{16}C B(E2, $2^+ \rightarrow 0^+$) = 0.26 W.u. → Mn/Mp ~ 7.6

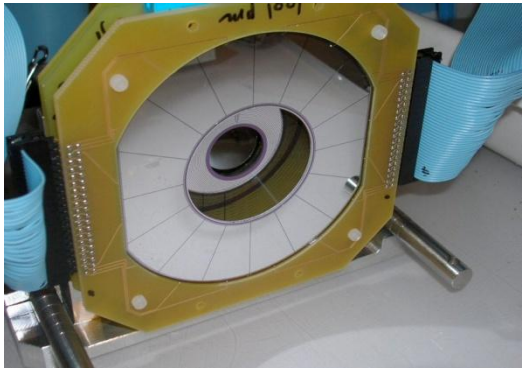
The ^{16}C Experiment

^{9}Be + ^{9}Be at 40 MeV → ^{16}C + 2p



γ-radiation detected with Clover Ge detectors.





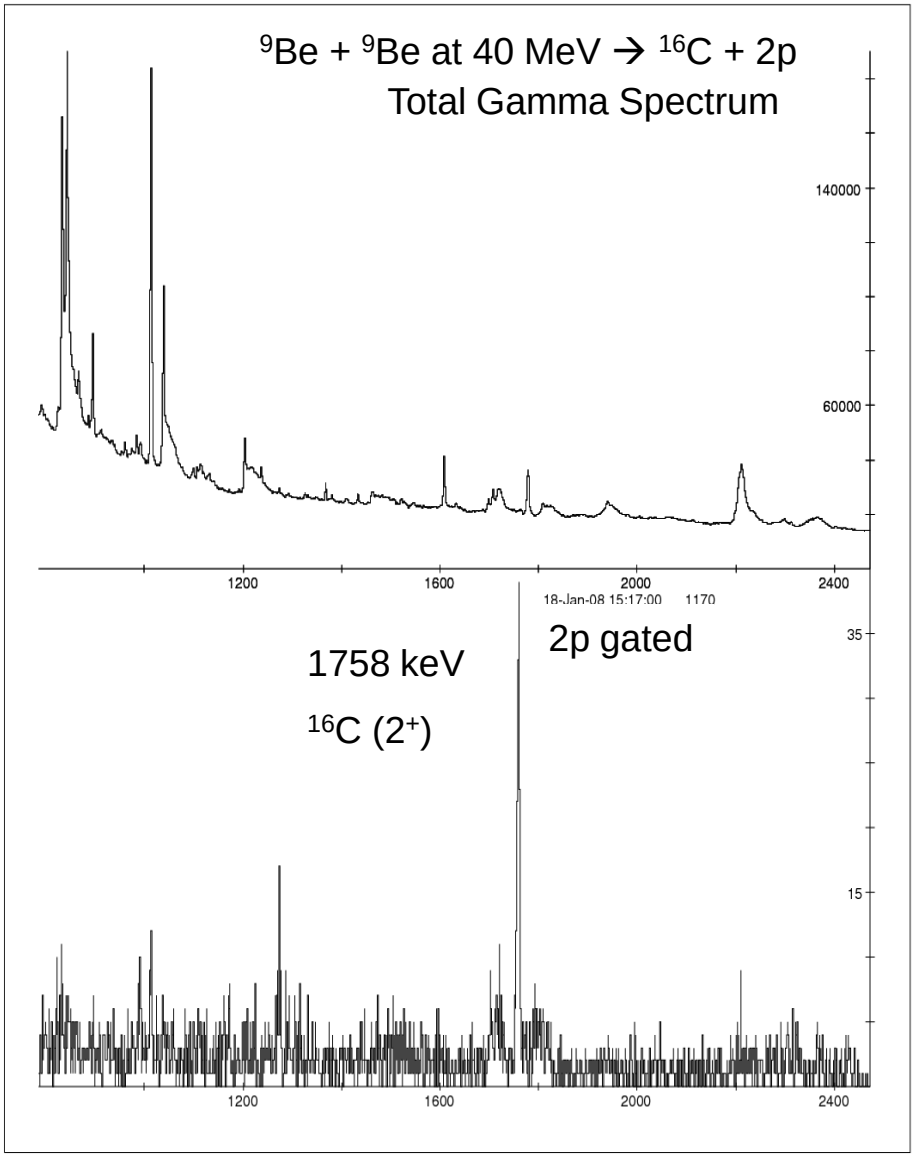
Charged particle detection with particle telescope ΔE-E.

Collaboration between Livermore and Berkeley National Laboratory Applied and Basic Research Program

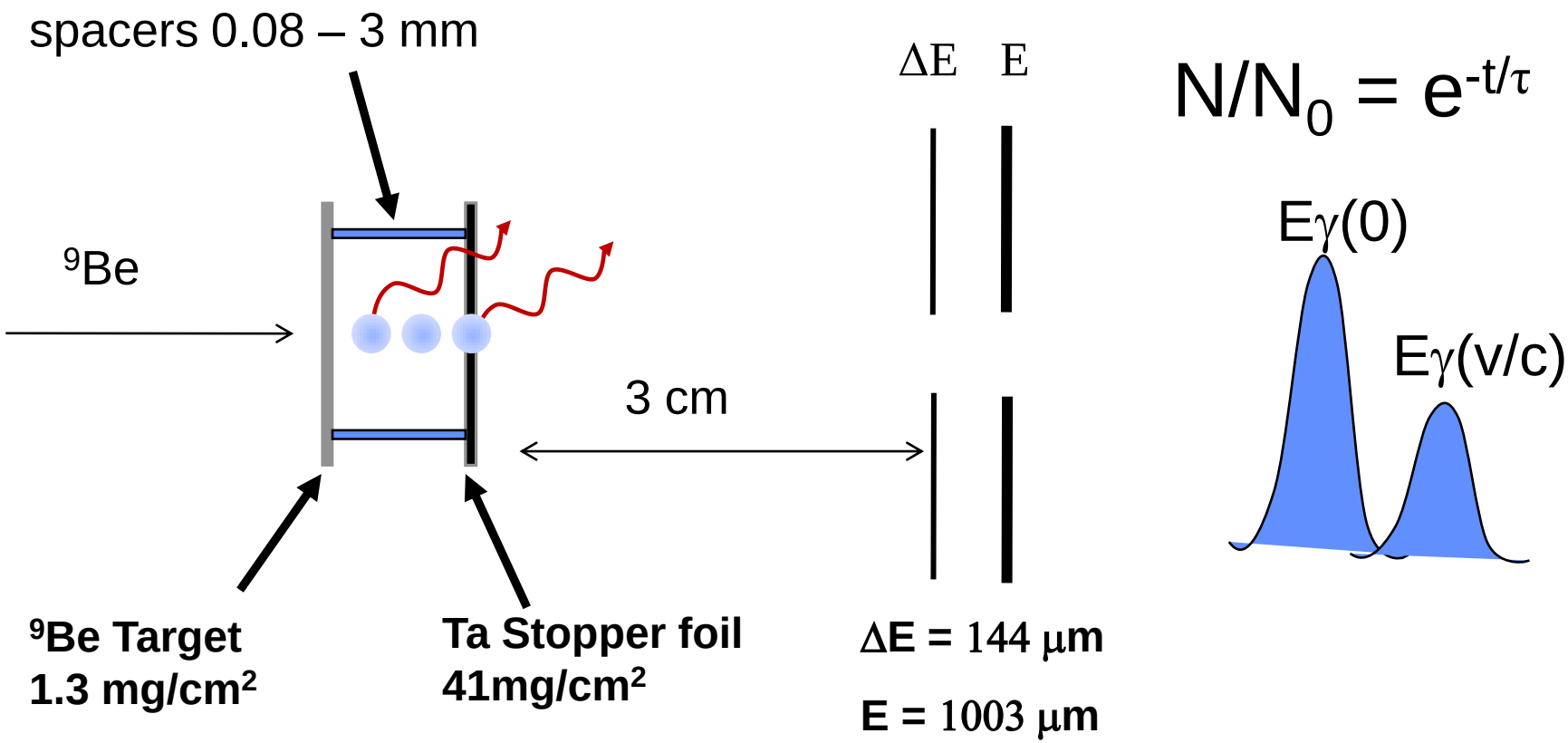
Channel Selection

2 Protons - a Clean Tag

- High binding-energy for protons
- Tune E* to suppress additional neutron evaporation
- Narrow Window ~ few MeV (c.m.)
- σ ~ 0.3mb (PACE)



Lifetime Measurement
Recoil Distance Method (RDM)



2p experiments

- **2p evaporation channel successfully extracted in 3 reactions.**
- **Best energies obtained from excitation function measurements**

^{12}C(^{7}Li,2p)^{17}N, beam energy 35 MeV

Predicted cross section 1.5 mb (PACE)

^{9}Be(^{9}Be,2p)^{16}C, beam energy 40 MeV

Predicted cross section 0.3 mb (PACE)

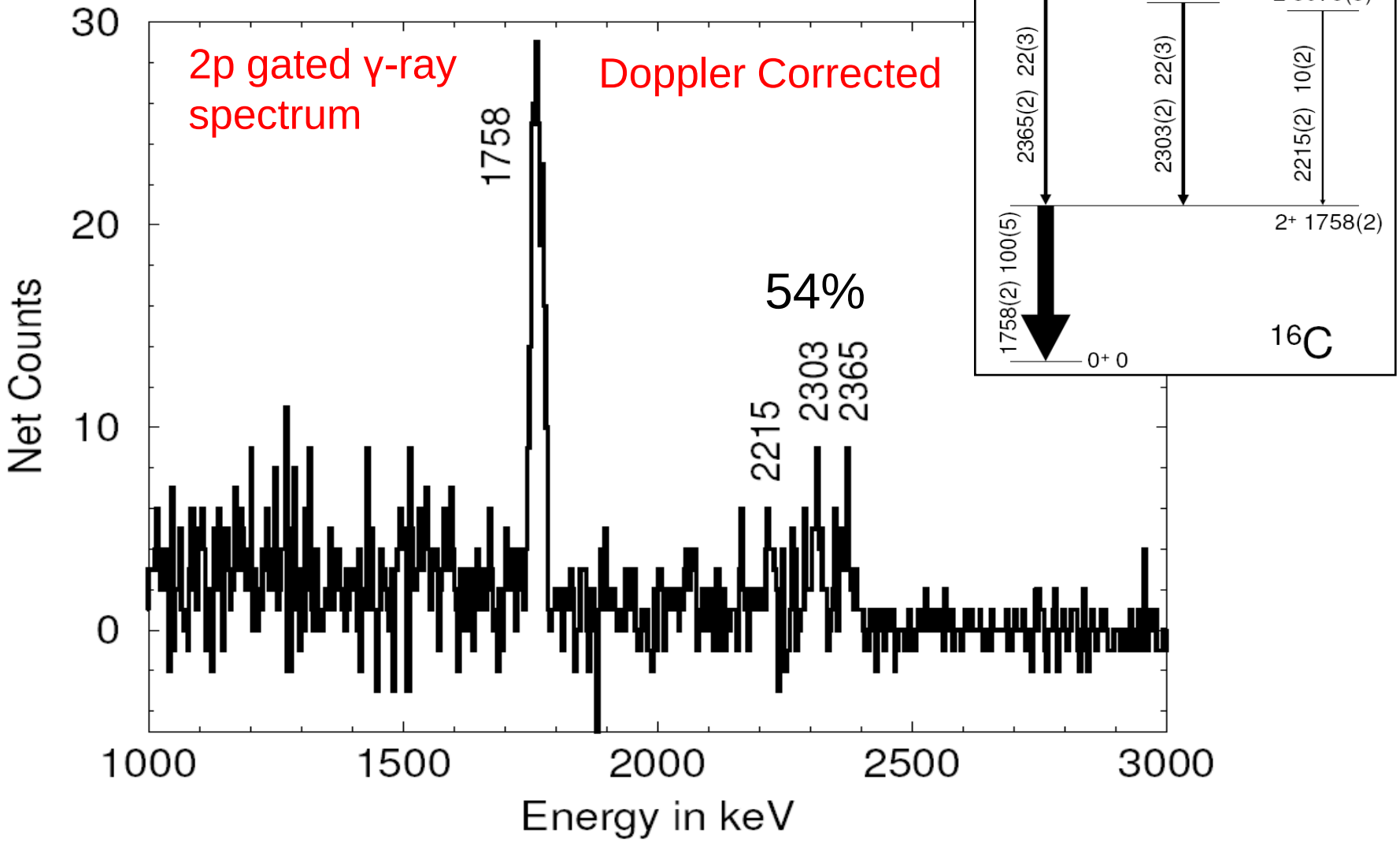
^{9}Be(^{11}B,2p)^{18}N, beam energy 50 MeV

Predicted cross section 0.2 mb (PACE)

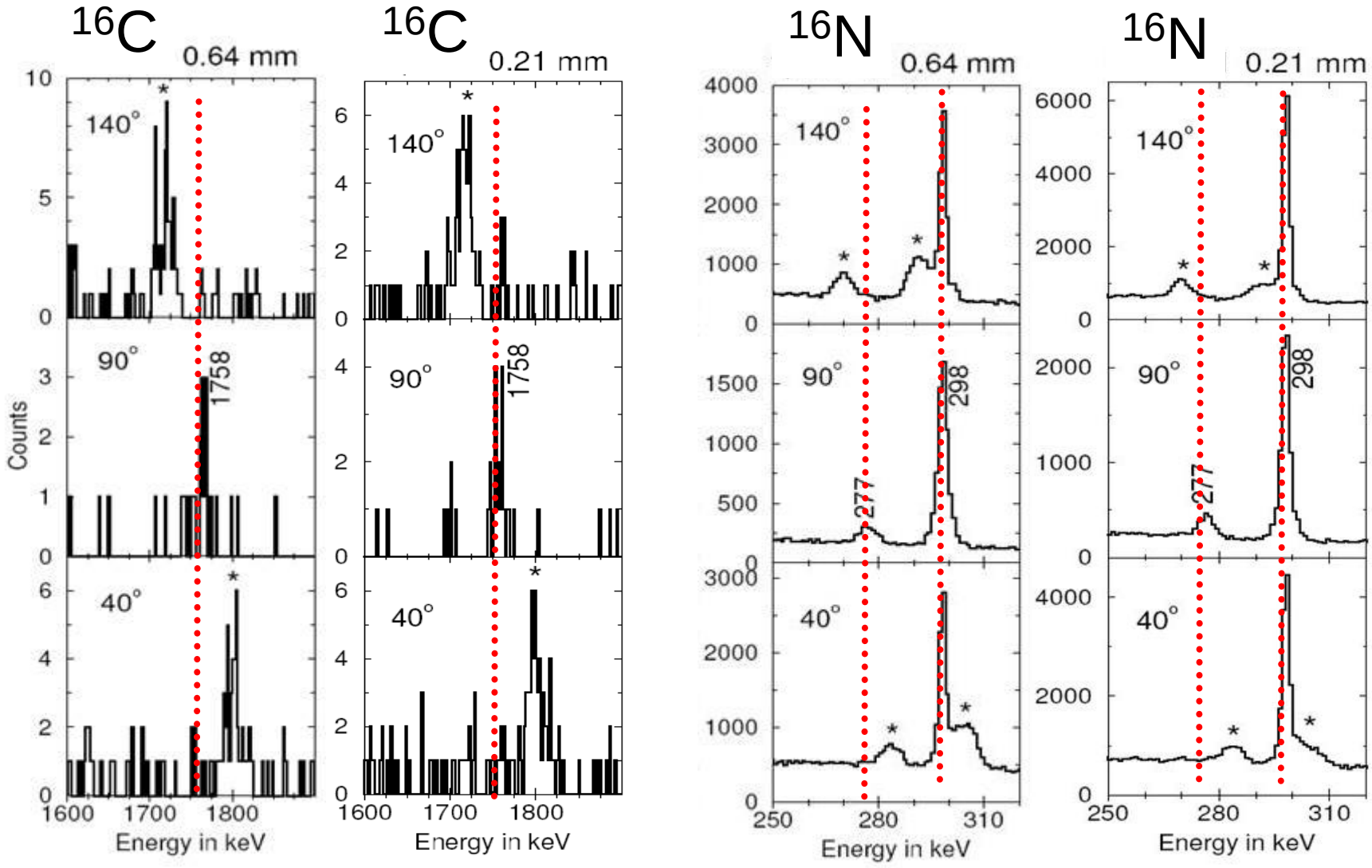
→ Lifetime B(M1) 2^- → 1^- (g.s)

Feeding of ^{16}C (2+)

^{9}Be(^{9}Be,2p)^{16}C at 40 MeV

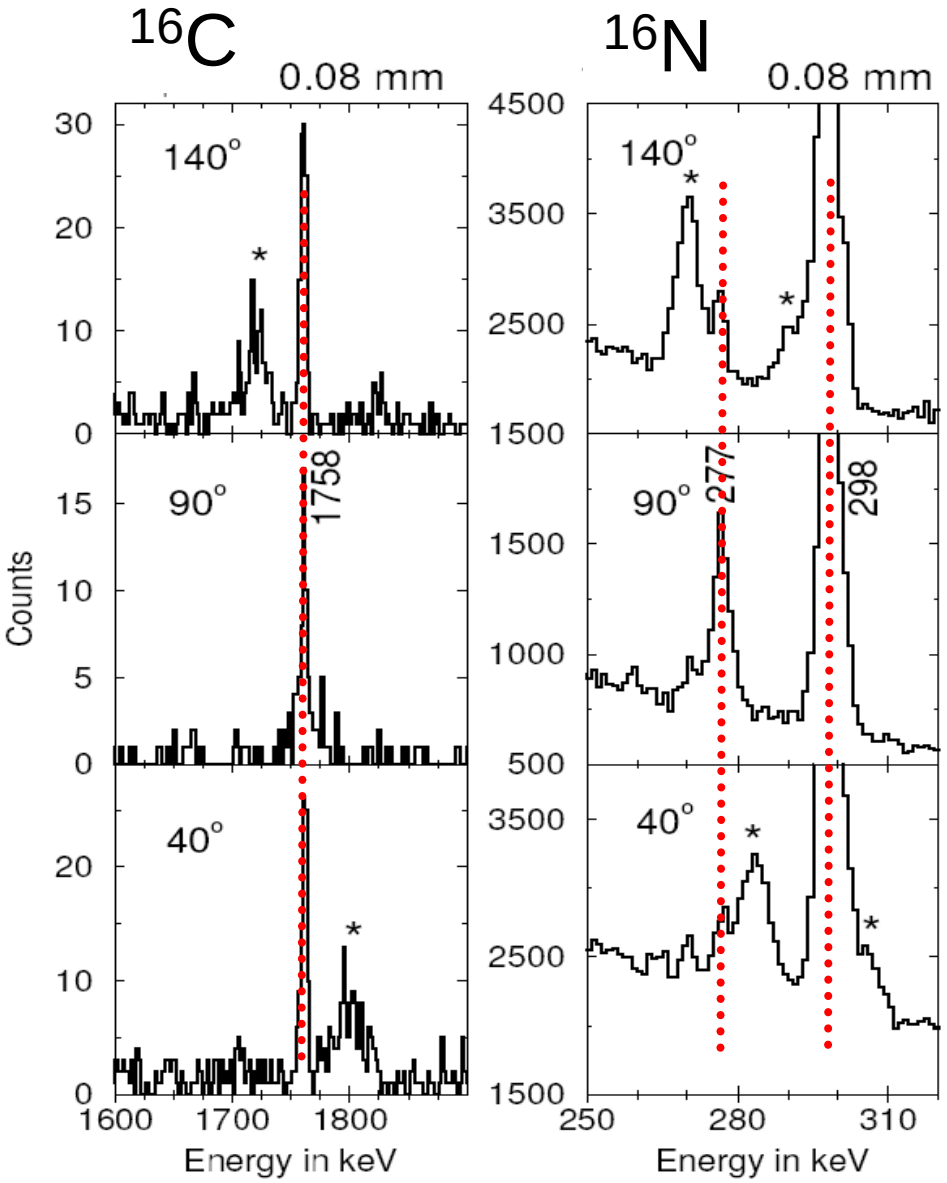


0.64 and 0.21 mm RDM Distance



^{16}N : 298 keV γ-ray 13 ps : 277 keV γ-ray 5.6 ps

^{16}C: 2$^+$ (0.08 mm RDM distance)



^{16}C 1758 keV: 47% stopped peak

Lifetime (t) = 11.7(20) ps.

B(E2; 2$^+$→0$^+$) = 4.15(73) e^{2}fm^4

^{16}C "feeding states" are fully shifted τ < 4ps

Lifetime (t) = 11.7(20) (-2.0) ps.

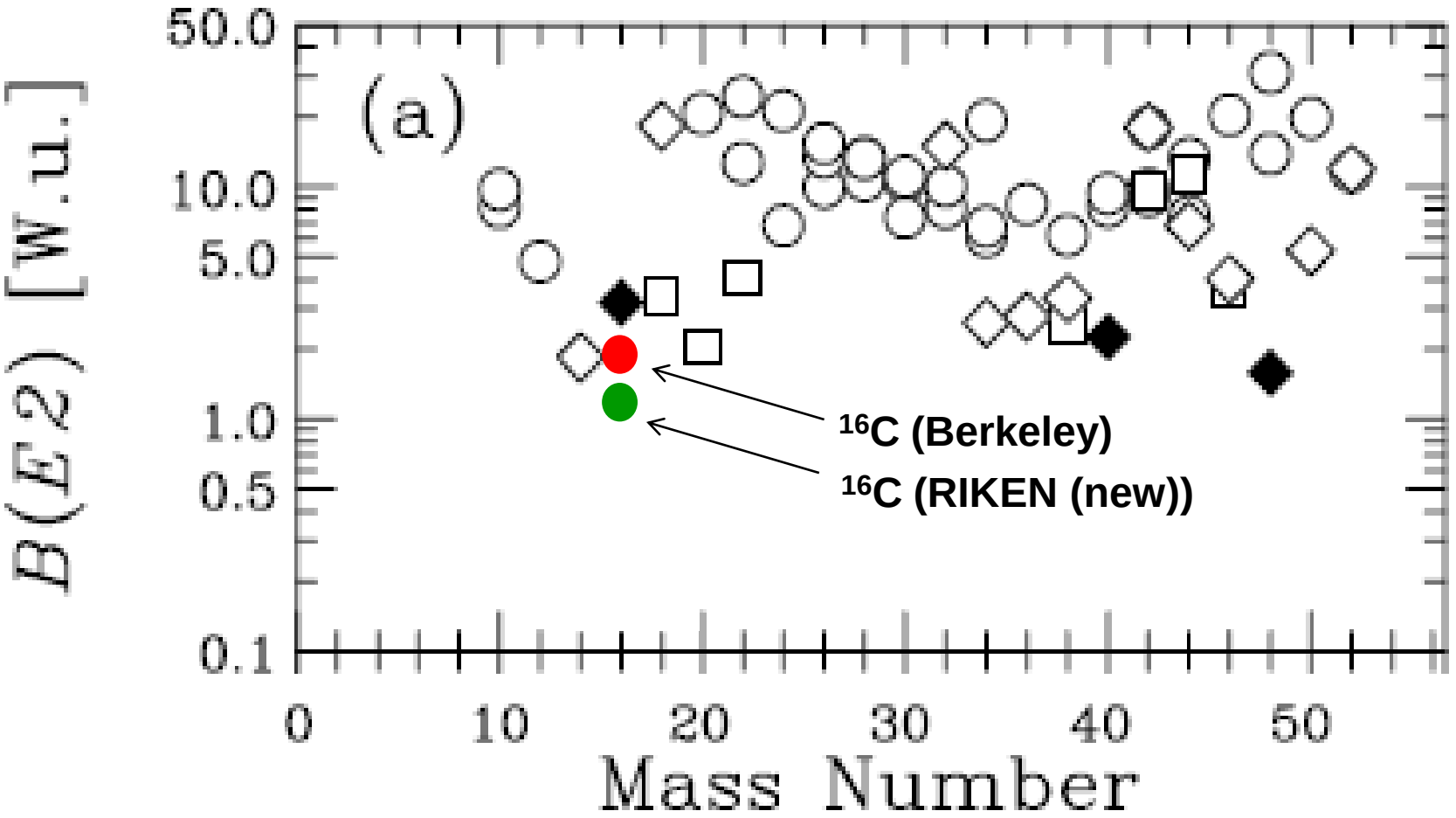
B(E2; 2$^+$→0$^+$) = 4.15(73) (+0.8) e^{2}fm^4

^{16}N 277 keV: 21% stopped peak

Measured τ = 5.6(10) ps

Published τ = 5.63(5) ps

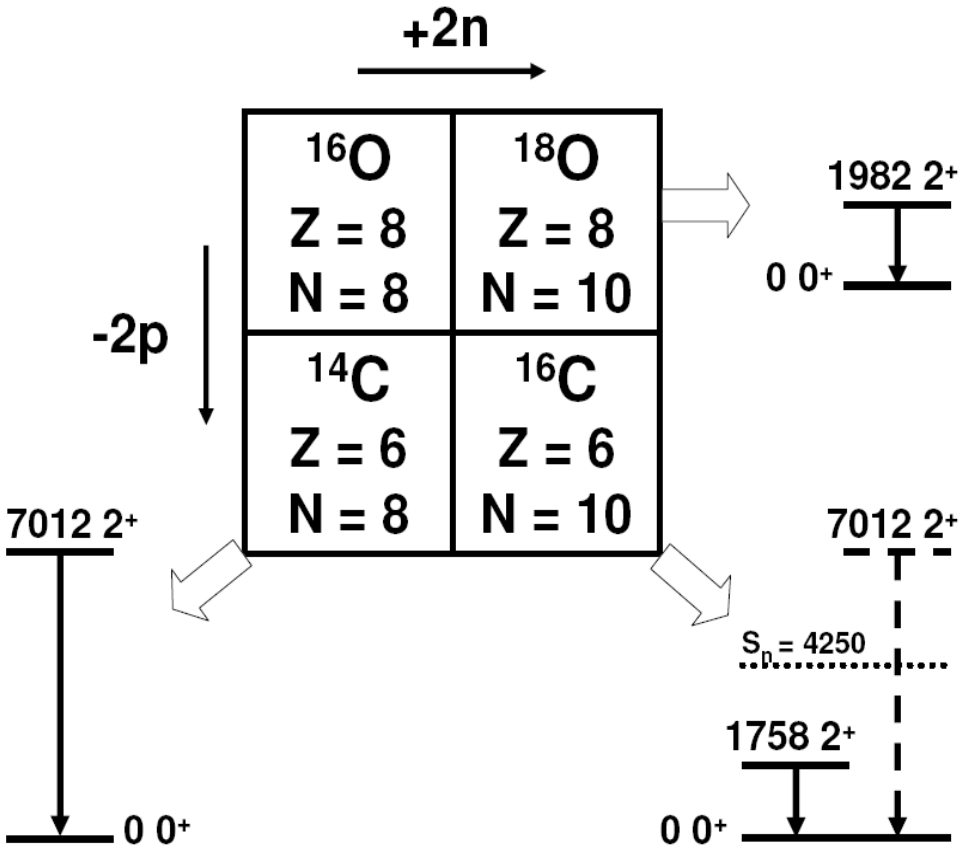
^{16}C: B(E2, $2^+ \rightarrow 0^+$) results



Comparing ^{16}C with Neighbors (I)

^{16}C and ^{18}O 2^+ state → dominant neutron excitation

B(E2) arises from the effective charge induced by *core polarization*.



^{18}O: B(E2) = 9.5(3) e^2fm^4

= 3.2 W.u.

^{16}C: B(E2) = 4.15(73) e^2fm^4

= 1.73 W.u.

Core polarization ~ Z^2

B(E2)^{18}O *$(6/8)^2$ = 1.8 W.u

~ B(E2) ^{16}C

Comparing ^{16}C with Neighbors (II)

Effective charges : *measure coupling between valence neutrons and proton core.*

- ^{16}C B(E2) reproduced in "USD" shell model with $e_n \sim 0.46$ (standard value e_n=0.5)
- ^{15}C $d_{5/2} \rightarrow s_{1/2}$ transition; derive $e_n \sim 0.4$
- $e_n \sim 0.4 \rightarrow {}^{16}$C B(E2;USD) ~ 3 e^2fm^4 → proton admixture

$$B(E2) \approx \left| \alpha \langle USD | E2 | USD \rangle + \beta \langle p^{-2} | E2 | p^{-2} \rangle \right|^2$$

4.15 e^2fm^4 from ^{16}C — 3 e^2fm^4 from USD model — 3.7 e^2fm^4 from ^{14}C

$$\left| 2_1^+; {}^{16}C \right\rangle = 0.97 \left| \nu (ds)^2 \right\rangle + 0.24 \left| \pi (p)^{-2} \right\rangle$$

94% **6%**

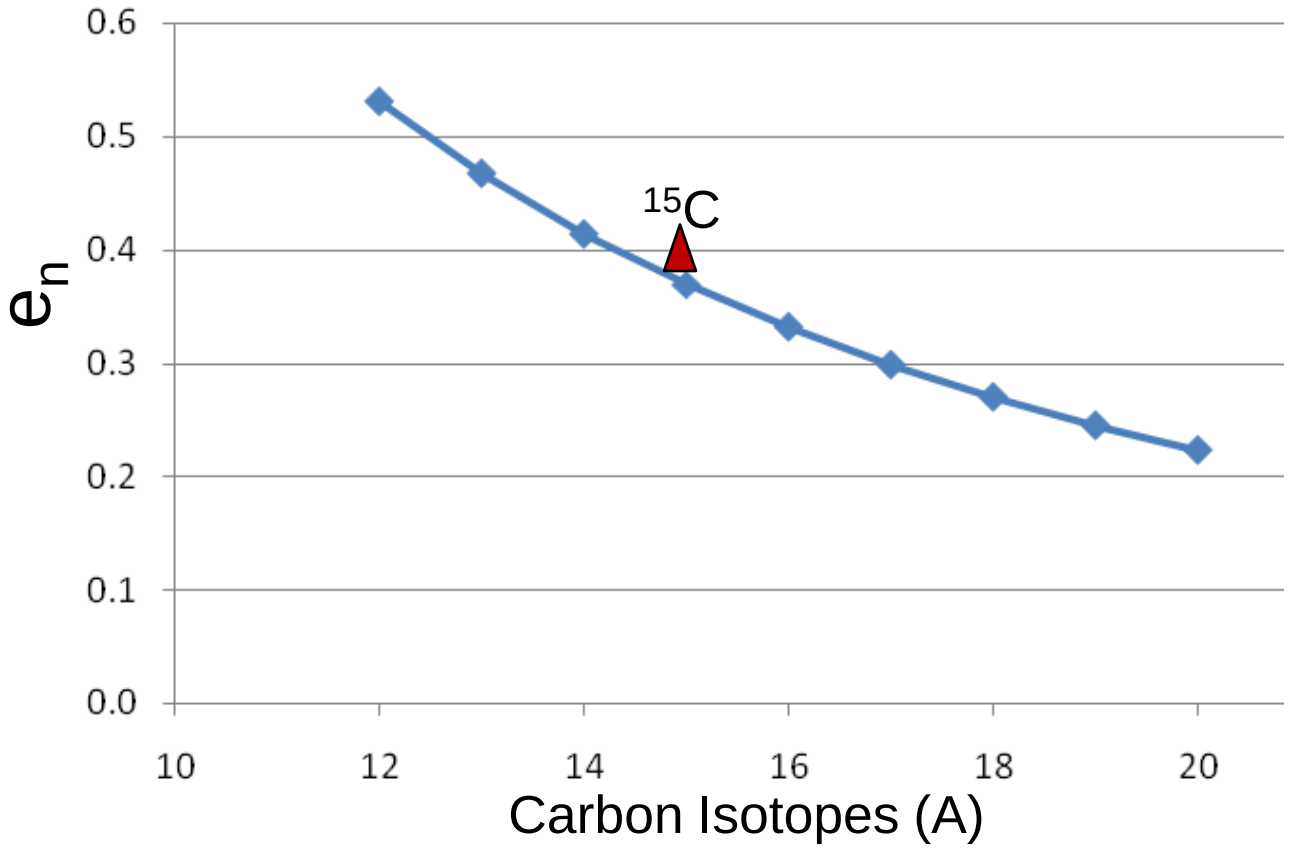
Interaction matrix element V in β between proton holes and neutrons is ~ 1MeV.

→ Consistent with p^{-1} and $(sd)^4$ value in ^{19}F

Arima and Hamamoto, Ann. Rev. Nucl. Sci. 21 (1971).

Isospin Dependence of Effective Charges (Bohr Mottelson Vol 2)

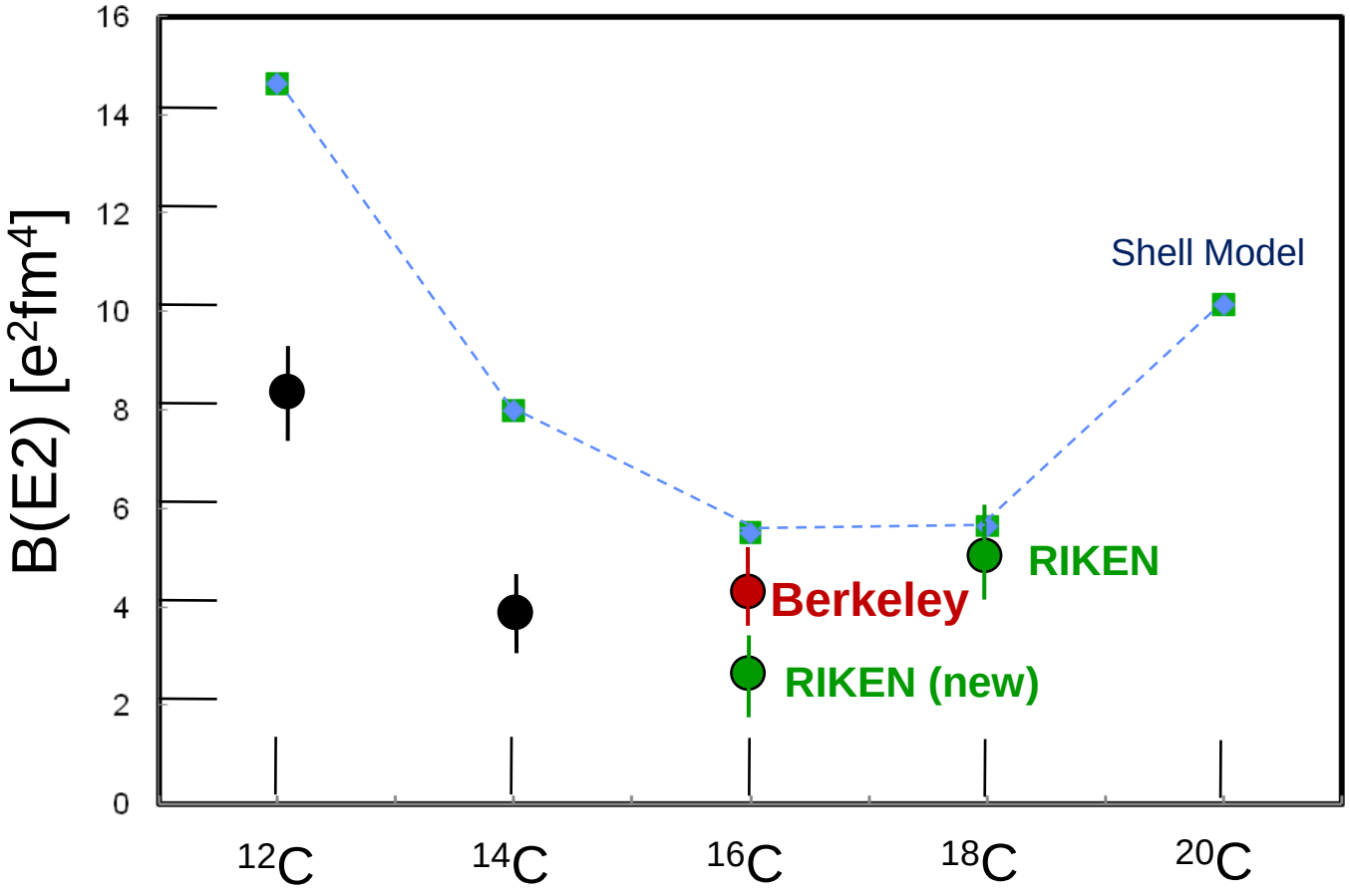
Sagawa et al PRC 70 (2004) 054316



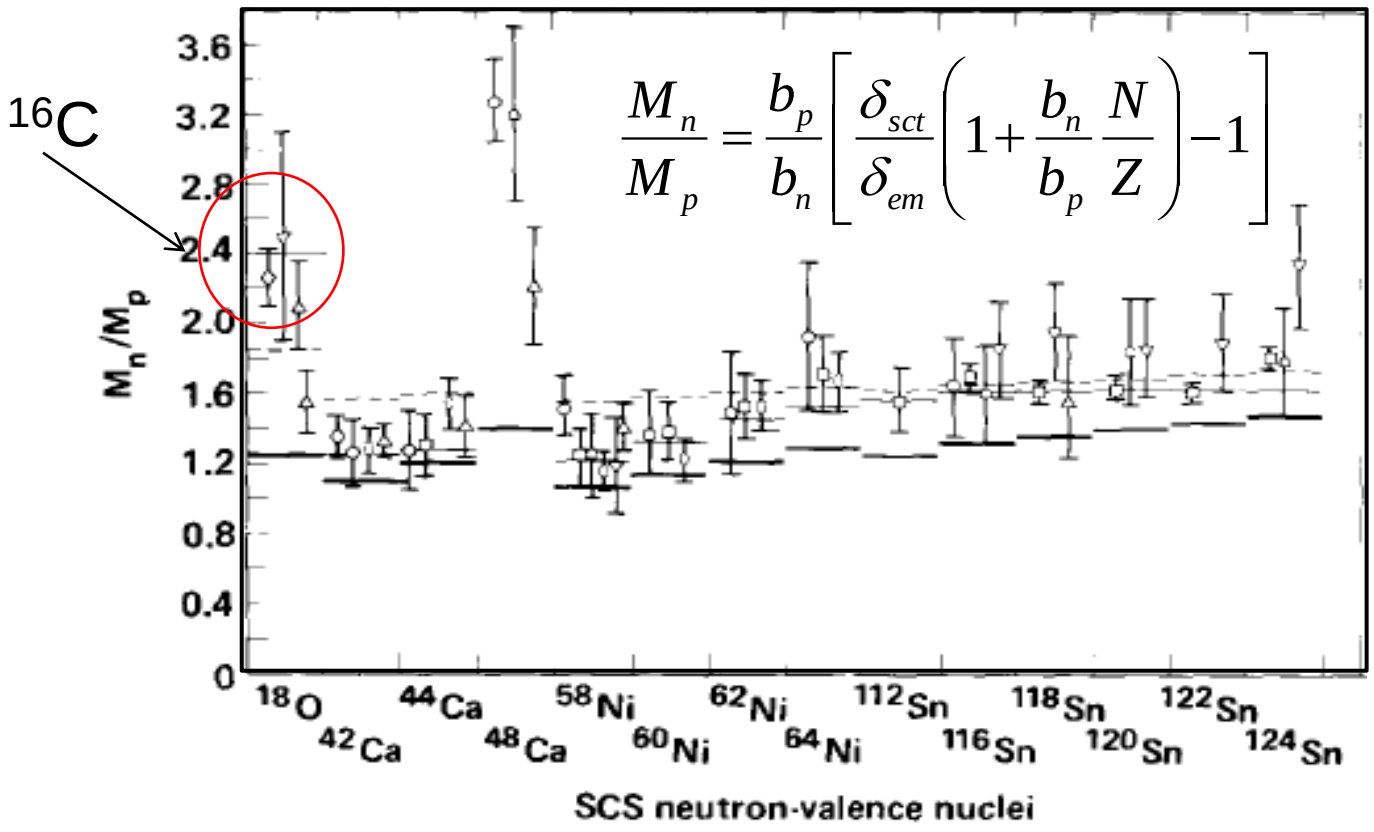
Carbon Isotopes B(E2) Systematics

Shell Model B(E2) - H. Sagawa et al., PRC **70**, 054316 (2004)

HF w.f; $eff_{n,p}(N/Z)$; Millener-Kurath (MK) interactions



^{16}C M_n/M_p



Combining our value of δ_{em} with the total "nuclear+Coulomb" deformation length δ_{sca} from inelastic scattering experiments: **Mn/Mp~2.4** Close to the value of ^{18}O.

Summary

- **Doppler shifted gamma-ray measurement $^{16}C(2^+ \rightarrow 0^+)$**

  $\tau(2+)$ = 11.7(20) ps

  B(E2) = 4.15(73) e^2fm^4 = 1.73(30) W.u

- **Value consistent with neighbors (^{18}O, ^{15}C)**

- **Effective charge e_n ~ 0.3-0.4**

- **Quantitative test of Shell Model**

- **Extract weak channels by gating on 2 charged particles with the STARS-LIBERACE array at LBNL. (^{16}C, ^{18}N, and ^{17}N)**

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