"The status of $^{12}C(\alpha,\gamma)^{16}O$, the `Holy Grail' of Nuclear Astrophysics"

A workshop in honor of the 85th birthday of Charlie Barnes

[brought to you by the Joint Institute for Nuclear Astrophysics (JINA)]

Logistics of the Meeting ...

- Lunch: Cafeteria or South Lake

You are here

4713 Alminar Ave
La Canada Flintridge, CA
91011

Travel 6.9 mi (about 10 mins)

Brad Filippone's Home
818-952-5470

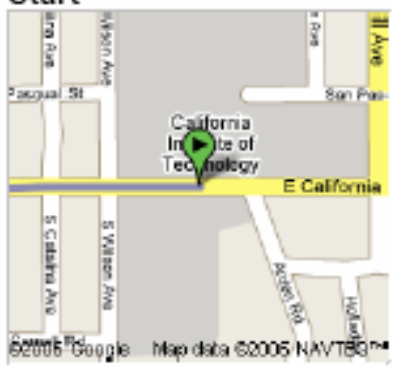
Getting to Dinner
Drinks: 7:00 PM
Dinner: 7:30 PM

Directions

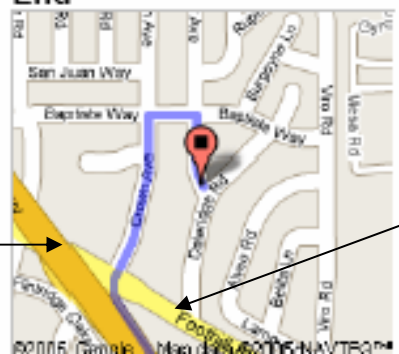
1.	Head **west** from **E California Blvd**	**1.4 mi** 3 mins
2.	Continue on **W California Blvd**	**0.2 mi**
3.	Turn **right** at **S Pasadena Ave**	**0.2 mi**
4.	Bear **left** into the entry ramp to **(I-210)**	**1.2 mi** 1 min
5.	Merge into **I-210 W**	**3.3 mi** 3 mins
6.	Take the **Foothill Blvd** exit	**0.2 mi**
7.	Bear **right** at **Crown Ave**	**0.2 mi**
8.	Turn **right** at **Baptiste Way**	**356 ft**
9.	Turn **right** at **Alminar Ave**	**0.1 mi**
10.	Arrive at 4713 Alminar Ave La Canada Flintridge, CA 91011	

Overview

Start



End



210 West Freeway

Foothill Blvd

Opening and Contributions of Charlie to $^{12}C(\alpha,\gamma)^{16}O$

- Order of 1st two talks inconsistent with history!
- I have not done Nuclear Astrophysics since ~ 1993
- My last talk on $^{12}C(\alpha,\gamma)^{16}O$ ~ 1993
  - Therefore let's re-use those slides!
    - Overview of the $^{12}C(\alpha,\gamma)^{16}O$ problem
    - The early measurements < 1993
    - Hope for the future
    - Some $^{12}C(\alpha,\gamma)^{16}O$ "Home Movies"
- My first encounter with Charlie...

Astrophysical Implications:

Uncertainties in $^{12}C(\alpha,\gamma)^{16}O$ ($\times 3 - \times 5$) give:

1. Large variations in Elemental Abundances after Stellar Burning.

2. Significant modifications to evolution of massive stars to Supernovae.

3. Uncertainties in what initial stellar mass = Black Ho

4. No obvious Big Bang effects (Whew!!)

"... single greatest experimental uncertainty in explosive nucleosynthesis." Arnett ('73)

What's the Problem??

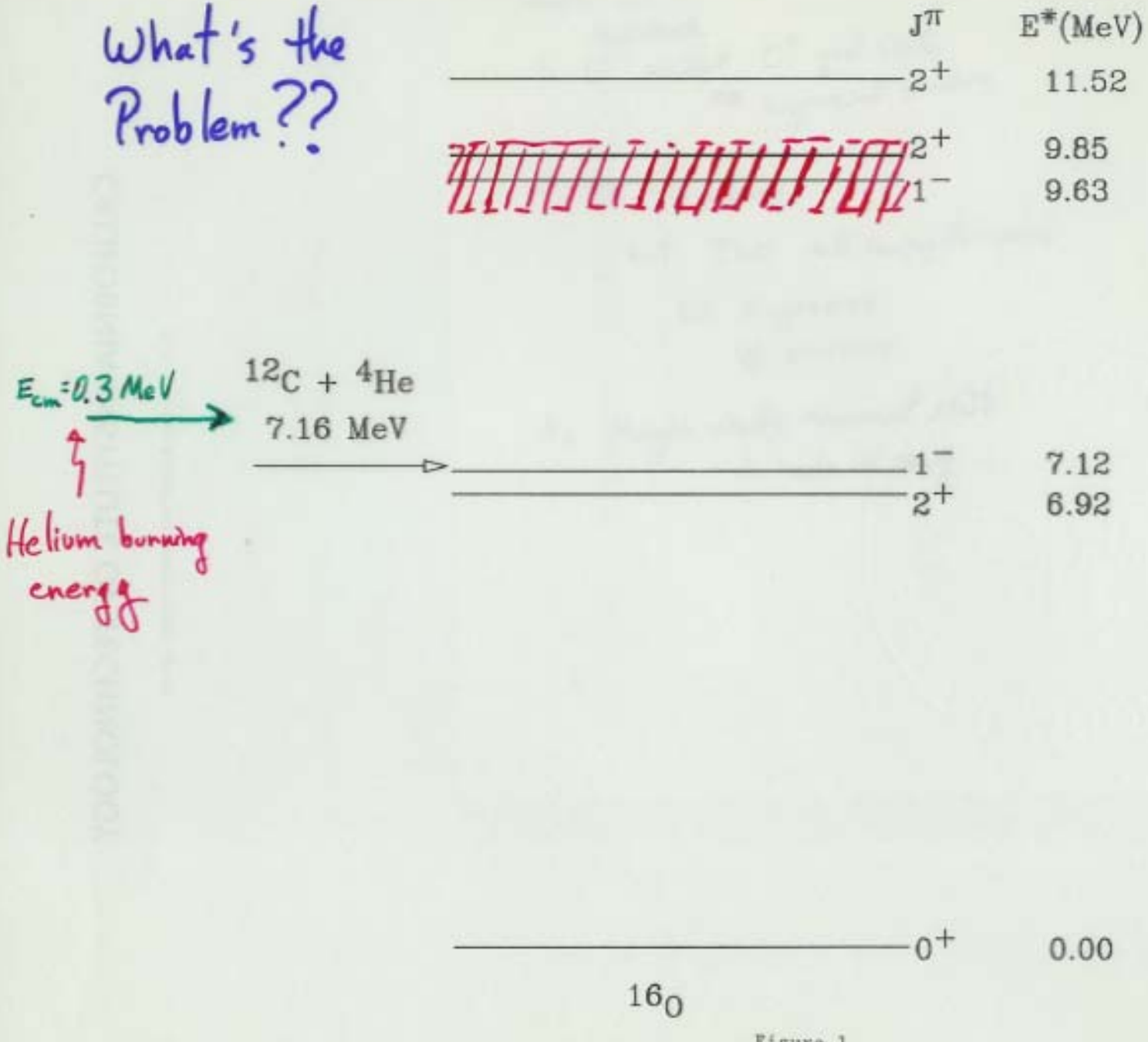


Figure 1

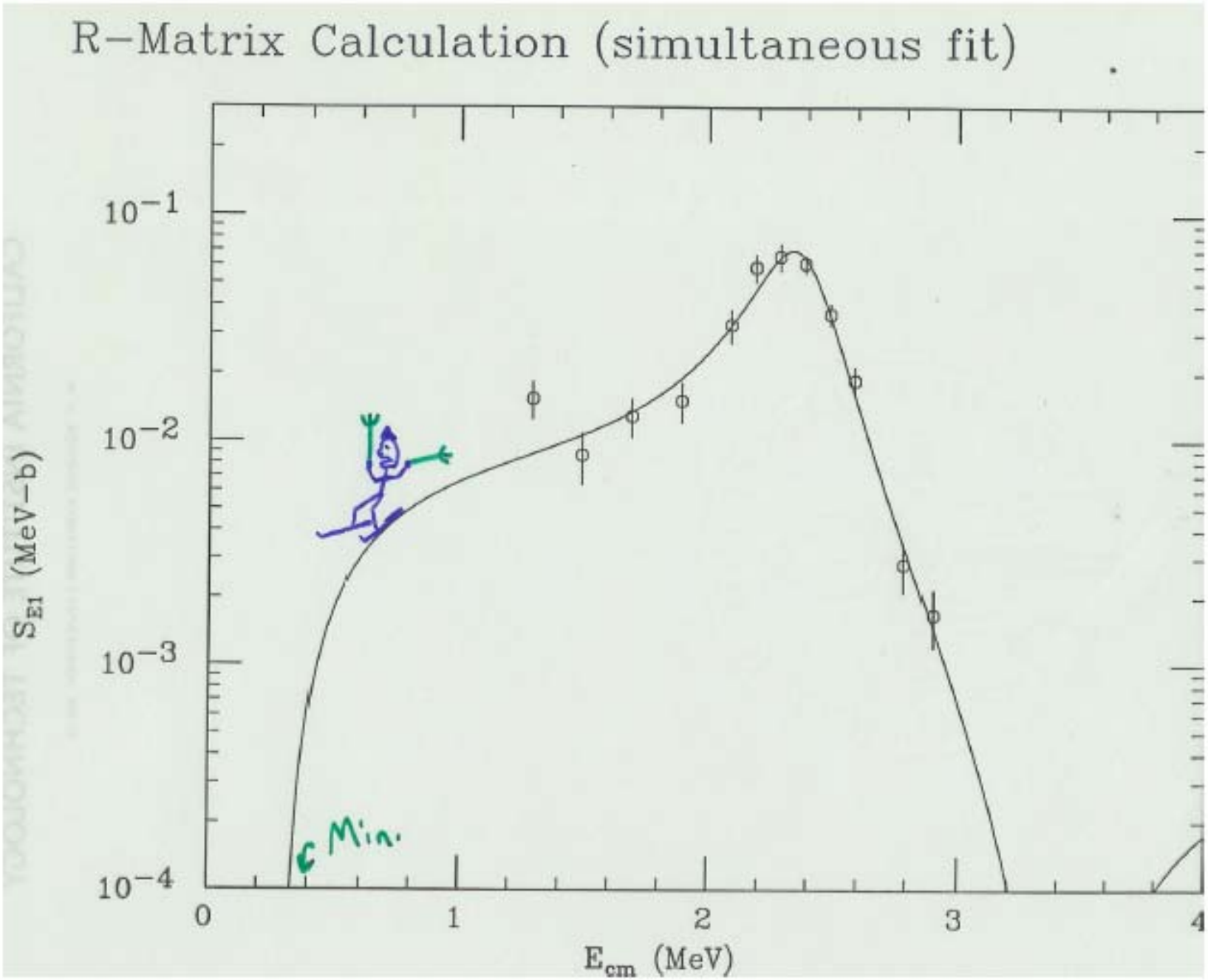
Contributions to $^{12}C(\alpha,\gamma)^{16}O$ @ Stellar Energies:

1. Isospin suppressed E1 capture from Sub-threshold State
2. " " " " " Broad 9.6 MeV state
3. " " " " " Higher lying 1^- states
4. E2 capture from Sub-threshold state
5. " " " Higher lying 2^+ strength
6. Cascades thru intermediate states

Note: E2 "tractable" with microscopic approaches

but E1 . . .

"The Devil is in the R-Matrix Calculation!!"



Contributions of Charlie to $^{12}C(\alpha,\gamma)^{16}O$

- It all began 85 years and 3 days ago in a small town in Canada (Toronto) ...
- PhD from Cambridge 1950
- Research Fellow, Caltech 1953
- Associate/Full/Emeritus Professor of Physics 1958 - Present

Relevant $^{12}C(\alpha,\gamma)^{16}O$ Publications for C. A. Barnes

- The $^{12}C(\alpha,\gamma)^{16}O$ cross section at low energies
  - C. A. Barnes, P. Dyer, M. R. Dwarakanath, D. C. Weisser, and J. F. Morgan
  - Proc. Of the Int. Conf. on Nuclear Physics, Vol. 1 Munich, Germany, Aug. 27-Sept 1, 1973, eds. J. deBoer & H. L. Mang, p. 363
- The $^{12}C(\alpha,\gamma)^{16}O$ reaction and stellar helium burning
  - P. Dyer and C. A. Barnes
  - Nucl. Phys. A223, 495 (1974)
- The $^{12}C(\alpha,\gamma)^{16}O$ Reaction: Its Role and Current Status
  - C. A. Barnes
  - *Advances in Nuclear Astrophysics*, ed. E. Vangioni-Flann 1987
- Coincidence measurement of the $^{12}C(\alpha,\gamma)^{16}O$ reaction cross section at low energies
  - R. Kremer, C. A. Barnes, K. H. Chang, H. C. Evans, B. W. Filippone, K. H. Hahn, and L. W. Mitchell
  - Phys. Rev. Lett. 60, 475 (1988)

- The β-delayed α-spectrum of ^{16}N and the ^{12}C(α,γ)^{16}O cross section at low energies

  L. Buchmann, R. E. Azuma, C. A. Barnes, J. M. D'Auria, M. Dombsky, U. Giessen, K. P. Jackson, J. D. King, R. G. Korteling, P. McNeely, J. Powell, G. Roy, J. Vincent, T. R. Wang, and P. Wren

  Phys. Rev. Lett. 70, 726 (1993)

- The β-delayed α-spectrum of ^{16}N and the low energy extrapolation of the ^{12}C(α,γ)^{16}O cross section

  L. Buchmann, R. E. Azuma, C. A. Barnes, A. Chen, J. Chen, J. M. D'Auria, M. Dombsky, U. Giessen, K. P. Jackson, J. D. King, R. G. Korteling, P. McNeely, J. Powell, G. Roy, M. Trinczek, J. Vincent, S. S. M. Wong, and P. Wren

  Proc. Of the 2nd Int. Sym. On Nuclear Astrophysics, Karlsruhe, July, 1992

  J. Phys. G 19(S), 115 (1993)

- A study of β-delayed α-emission from ^{16}N

  L. Buchmann, R. E. Azuma, C. A. Barnes, J. M. D'Auria, M. Dombsky, U. Giessen, K. P. Jackson, J. D. King, R. G. Korteling, P. McNeely, J. Powell, G. Roy, J. Vincent, S. S. M. Wong, and P. Wren

  Nucl. Instr. Meth. B79, 330 (1993)

- ^{12}C(α,γ)^{16}O and the β-delayed α-spectrum of ^{16}N

  C. A. Barnes

  Variations on a Nuclear Theme, a symposium in honor of Stanley S. Hanna, Stanford, CA, 1991

- Constraints on the low-energy E1 cross section of $^{12}C(\alpha,\gamma)^{16}O$ from the β-delayed α-spectrum of ^{16}N

  R. E. Azuma, L. Buchmann, F. C. Barker, C. A. Barnes, J. M. D'Auria, M. Dombsky, U. Giessen, K. P. Jackson, J. D. King, R. G. Korteling, P. McNeely, J. Powell, G. Roy, M. Trinczek, J. Vincent, T. R. Wong, S. S. M. Wong, and P. Wren

  Phys. Rev. C50, 1194 (1994)

- The β-delayed α-spectrum of ^{16}N, and its role in defining the astrophysical cross section from $^{12}C(\alpha,\gamma)^{16}O$

  C. A. Barnes

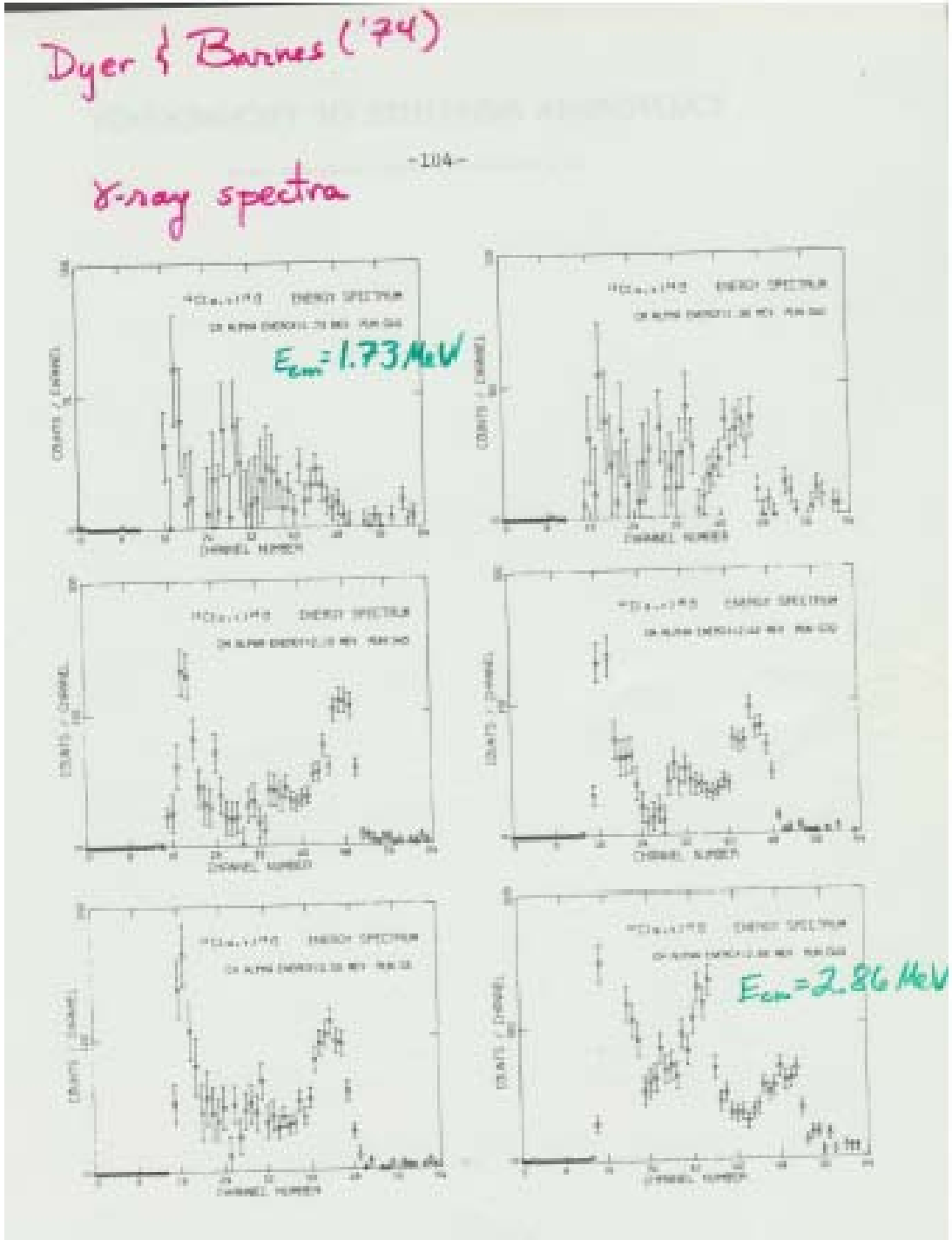
  Nucl. Phys. A588, 295c (1995)

- Analysis of the total $^{12}C(\alpha,\gamma)^{16}O$ cross section based on available angular distributions and other primary data

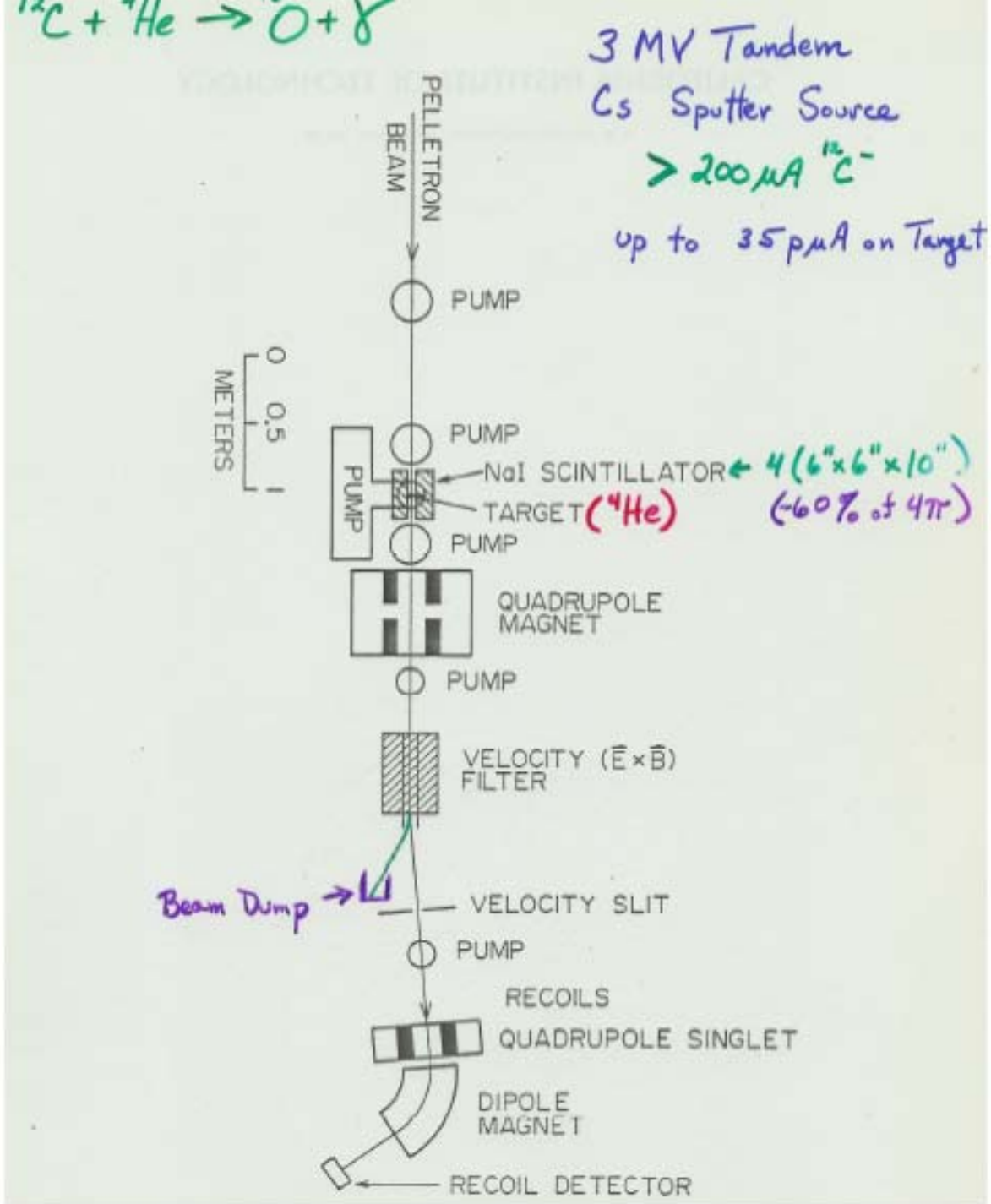
  L. Buchmann, R. E. Azuma, C. A. Barnes, J. Humblet and K. Langanke

  Phys. Rev. C54, 393 (1996)

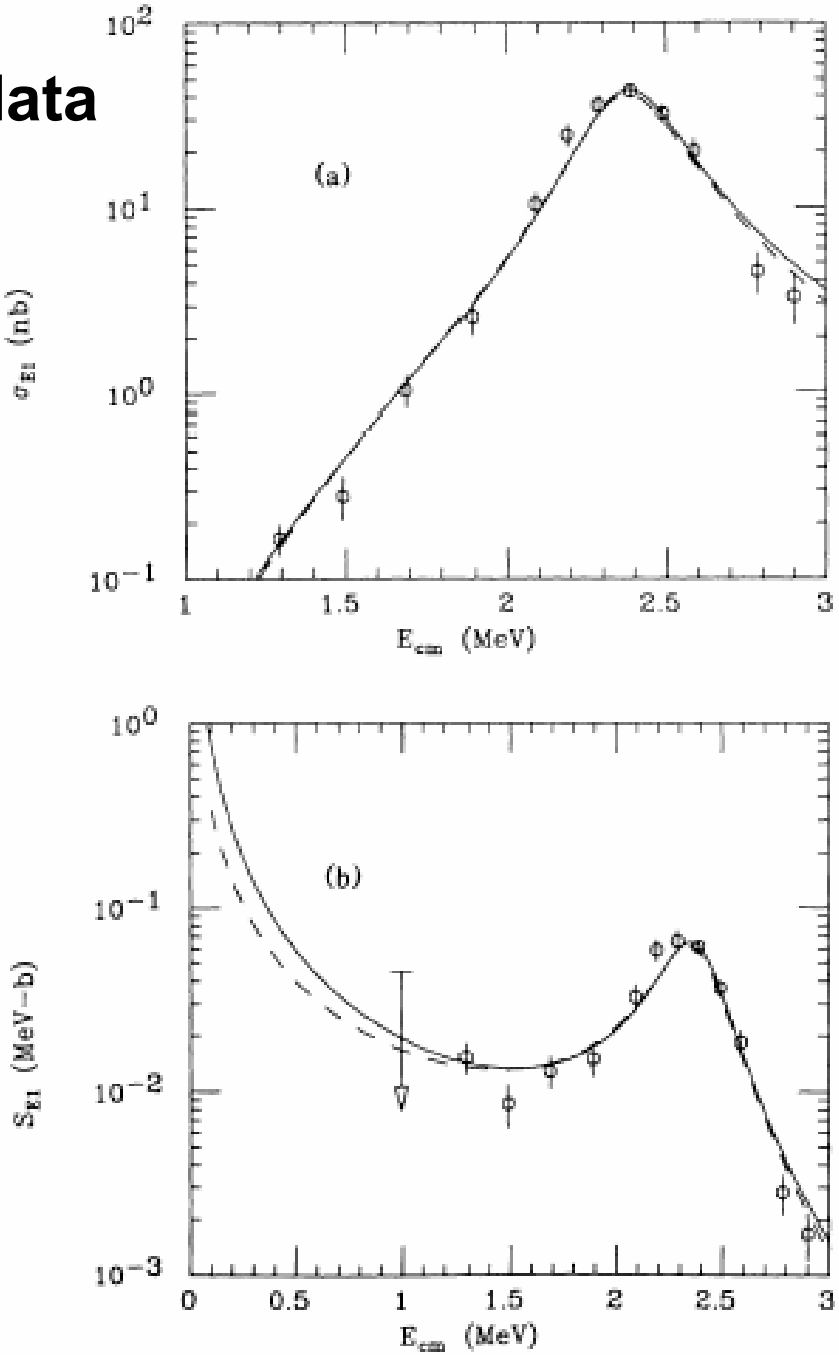
The Dyer and Barnes Data (1974)



Kremer, et al experiment (1988)



Kremer, et al data (1988)

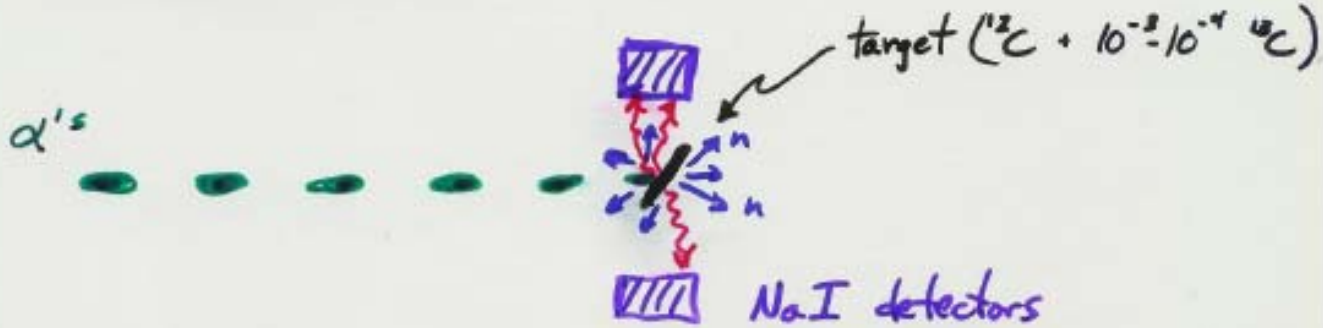


The Experiments:

After early attempts - large uncertainties in data

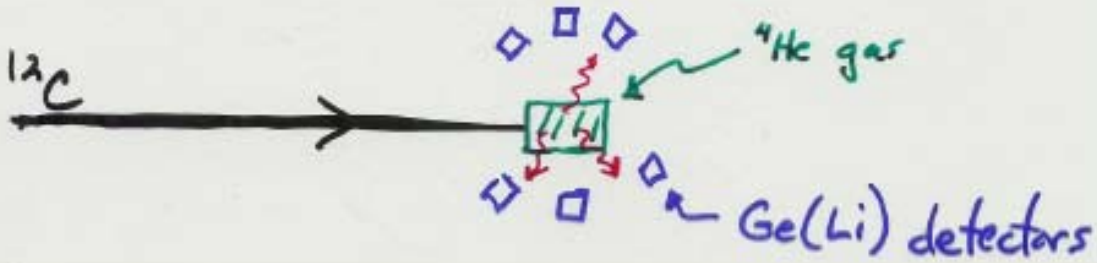
Then...

('74) Dyer & Barnes (Caltech)

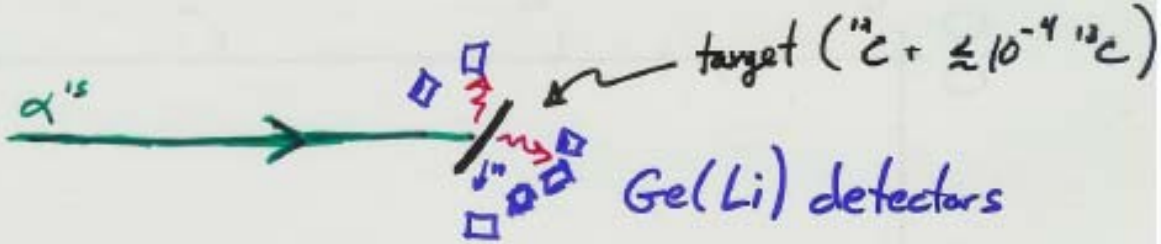


⇒ Pulsed α beam + n/γ T.O.F. difference → reject n's

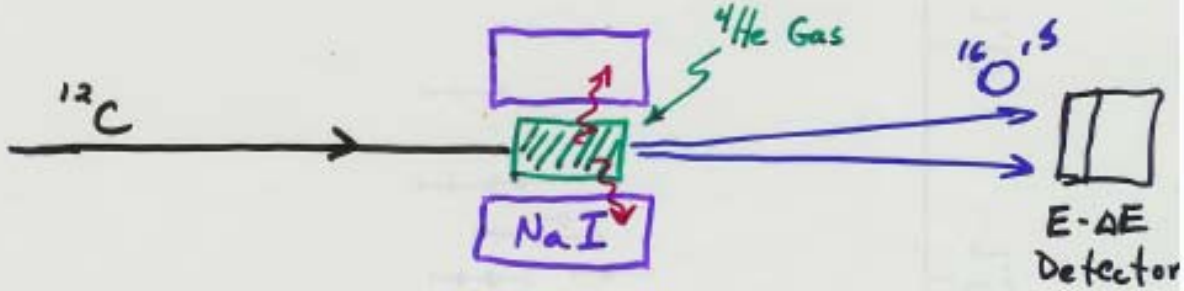
('82) Kettner et al (Münster)



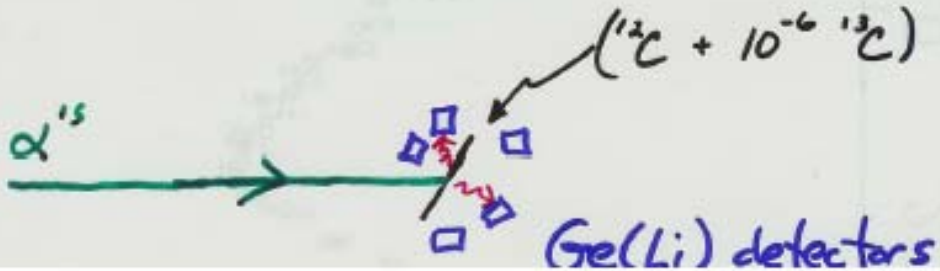
('87) Redder et al (Münster)

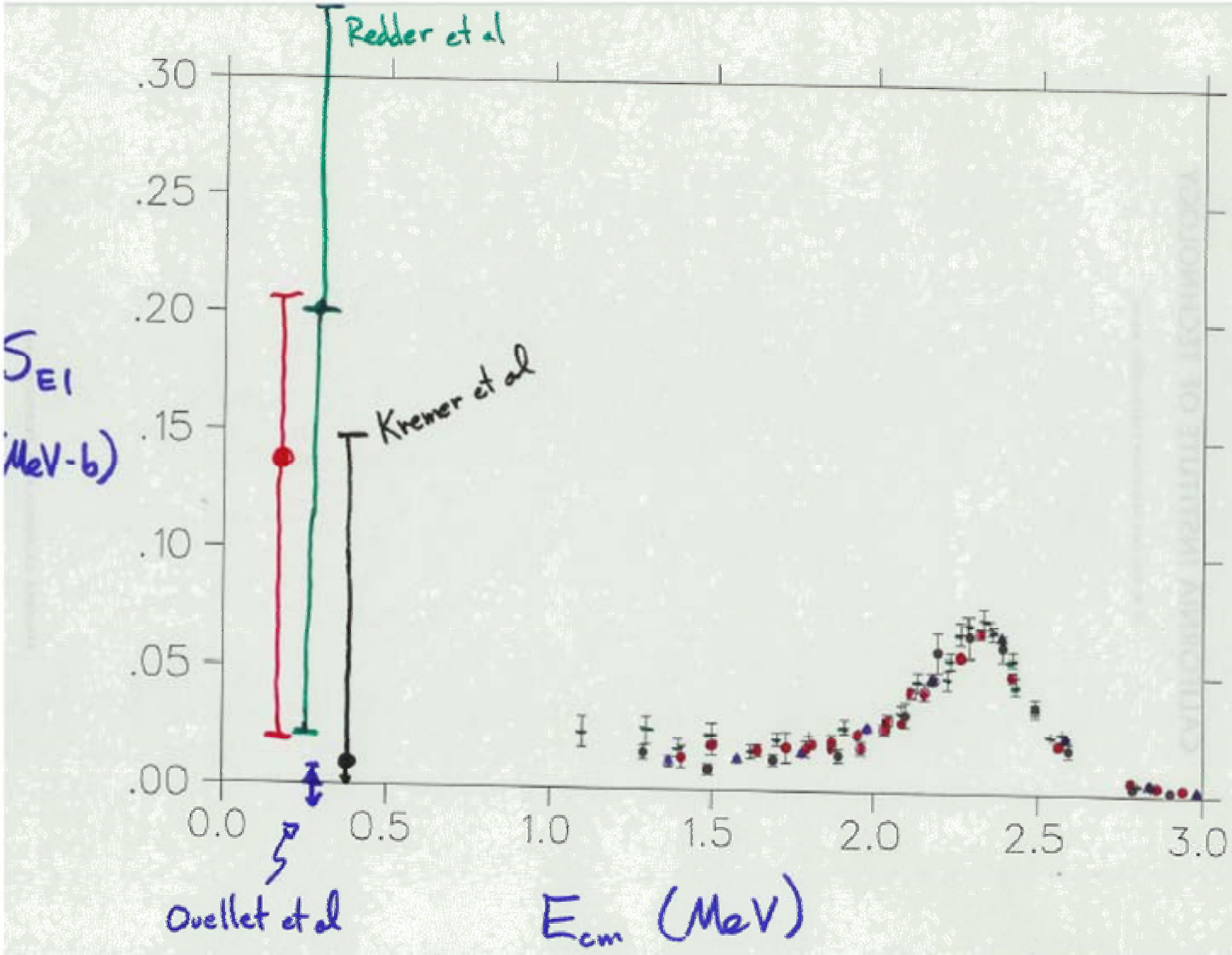


('88) Kremer et al (Caltech)



('92) Ouellet et al (Queen's U.)




Redder et al
Kremer et al
Ouellet et al
S_{E1}
(MeV-b)
E_{cm} (MeV)
.30
.25
.20
.15
.10
.05
.00
0.0
0.5
1.0
1.5
2.0
2.5
3.0

CALIFORNIA INSTITUTE OF TECHNOLOGY

W. K. KELLOGG RADIATION LABORATORY 106-38

February 16, 1988

Professor Stanford Woosley
Board of Studies in Astronomy & Astrophysics
University of California
Santa Cruz, CA 95064

Dear Stan,

The $^{12}C(\alpha,\gamma)^{16}O$ situation is incomprehensible to me. If the results of Filippone et al are correct then Dyer and Barnes and Redder et al were measuring background radiation as well as that from $^{12}C(\alpha\ \gamma)^{16}O$.

Caughlan and Fowler (1988) will publish results based long ago on Redder et al in which S(300 keV, E1) = 0.16 MeV-barns and S(300 keV, E2) = 0.108 MeV-barns so S(300 keV) = 0.268 MeV-barns. I attach a copy of Thermonuclear Reac$ Rates V. See Table II 5 and Table III 11. We will add a footnote recommendir that users also consider multiplying the reaction rate by 0.5!

Uncertainly yours,

William A. Fowler

WAF:mw
cc: B. Filippone
J. Humblet
G.R. Caughlan
C.H. Barnes
Enclosure: Thermonuclear Reaction Rates V

We will ask Jan Lang to send you a copy

State University of New York at Stony Brook
Stony Brook, New York 11794-3800
telephone: (516) 632-~~8160~~ 7985

StonyBrook

MEMORANDUM

To Brad Filippone
From Gerry Brown
Subject 18 Mg Stars
Date 23 May, 1991.

Dear Brad,

It seems that the demise of the prompt explosion may have been reported prematurely. With the lower $^{12}C(\alpha,\gamma)^{16}O$ rate you now have, half the Fowler / Caughlan value, the 18 Mg stellar cores become like previous 15 Mg ones which Steve Bruenn can blow!

All best regards,

Gerry

Anyway, the rate is very important.

2'll be out for Willy's B-day

Hope for the Future?

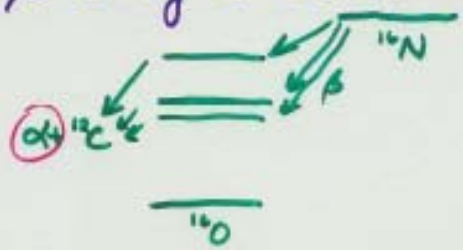
1. Perhaps higher energy $^{12}C(\alpha,\gamma)^{16}O$ data can better characterize Background Strength. (R-Matrix Fits)

2. α transfer Reactions with Gamma Ray Coincidence ?! eg $^{12}C(^{7}Li, t\gamma)^{16}O$

   $\Rightarrow$ "Gives" $\frac{\Gamma_\alpha \Gamma_\gamma}{P_\ell(\alpha)}$ vs. E_{cm} a.k.a. $S(E)$

   $P_\ell(\alpha)$: α penetrability

3. ^{16}N β decay to α unbound states in ^{16}O



4. Combination of all info. to get $S(E)$! with "small" uncertainty

$^{12}C(\alpha,\gamma)^{16}O$ as officially recognized by the Public Broadcasting System (PBS)