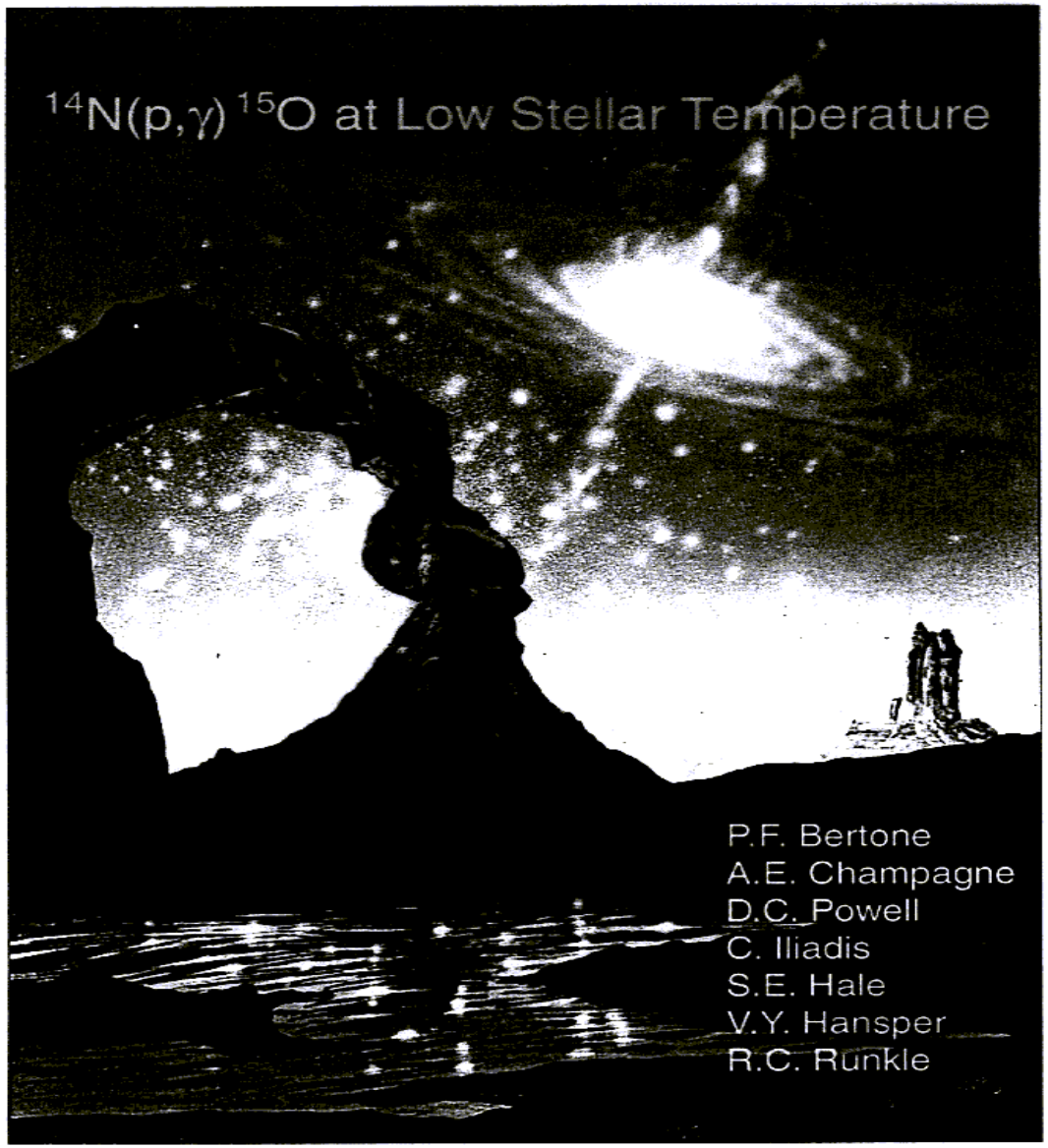
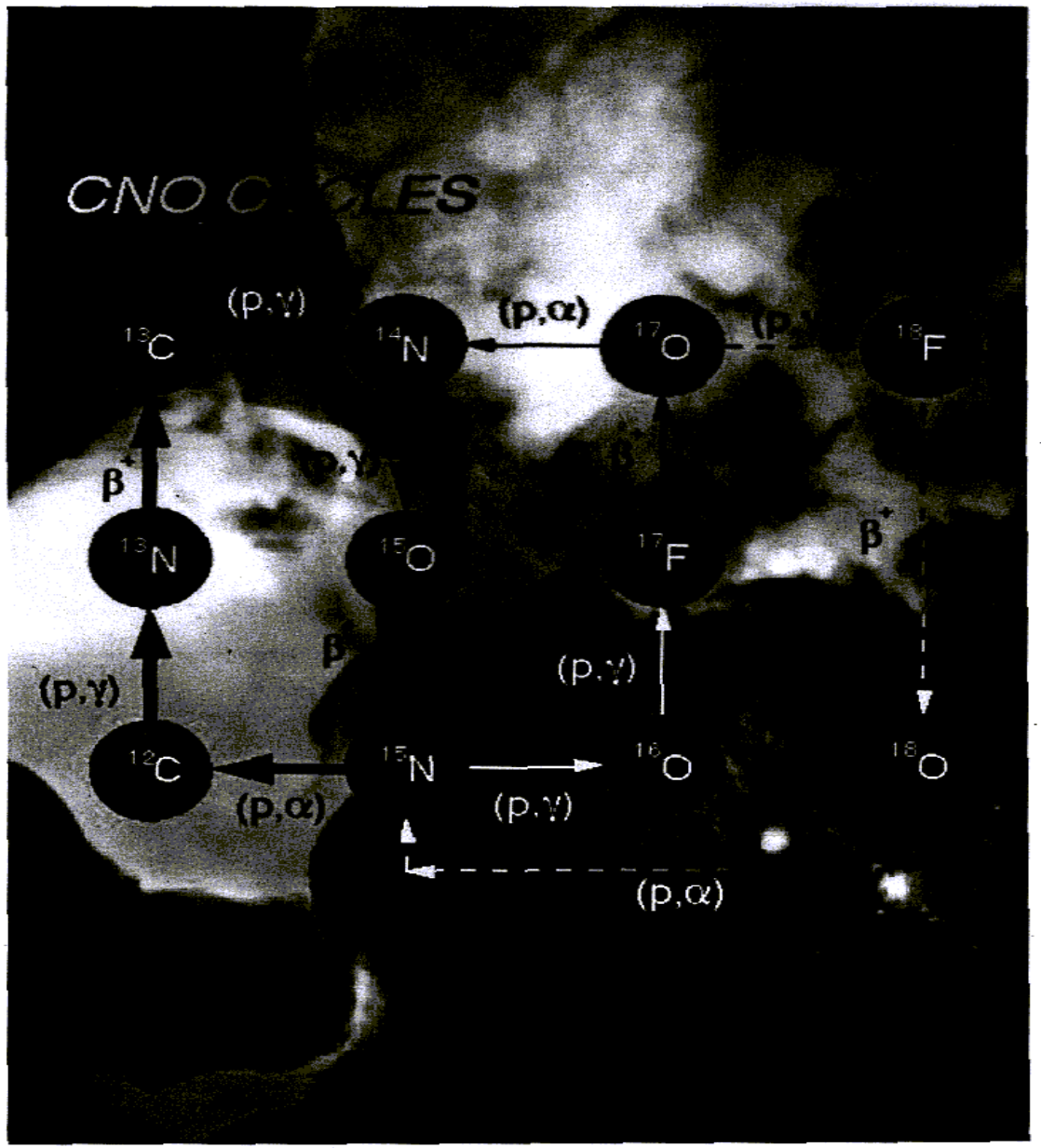
$^{14}N(p, gamma)^{15}O$ at low stellar temperatures

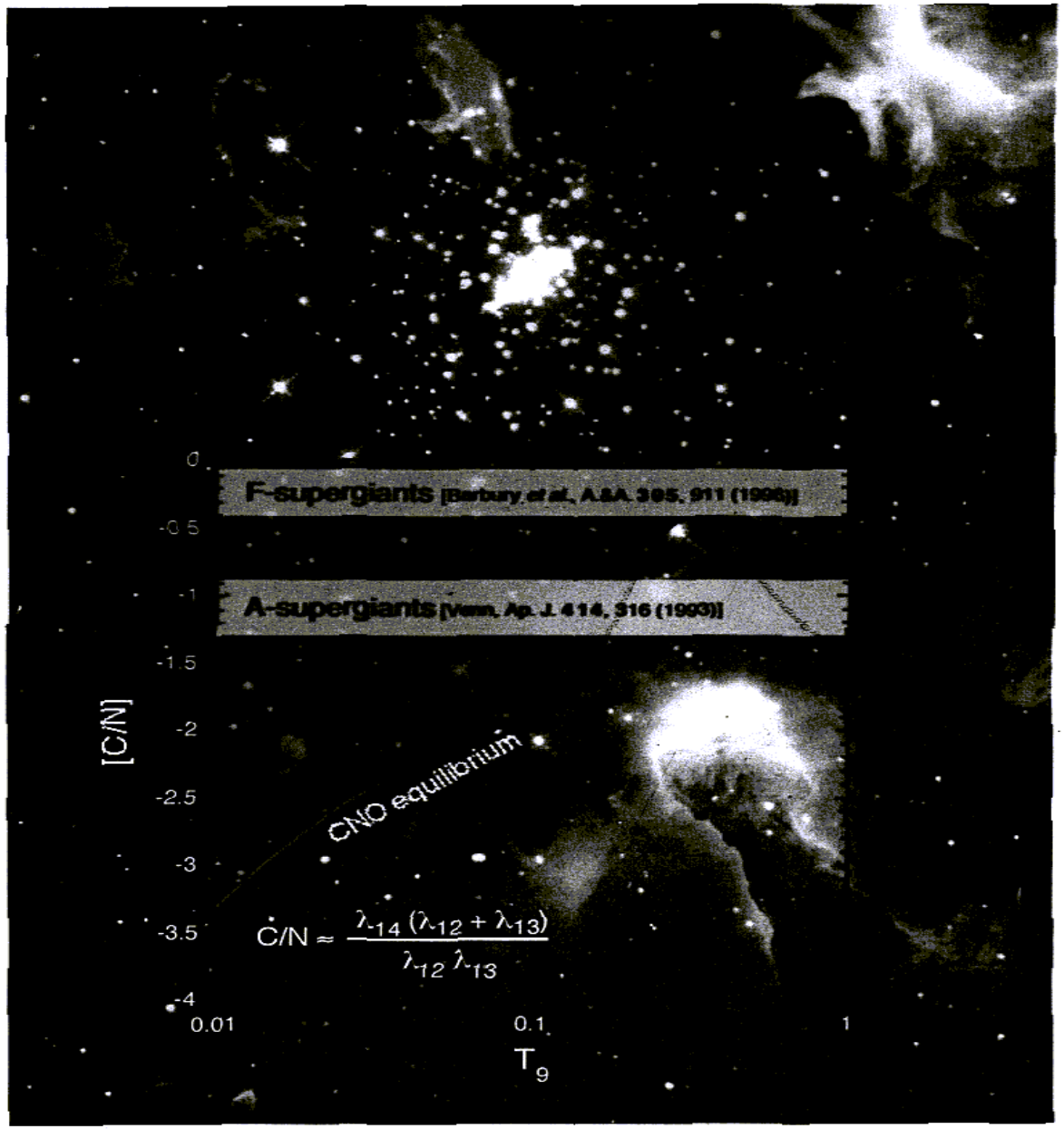
A. E. Champagne

$^{14}N(p,\gamma)^{15}O$ at Low Stellar Temperature

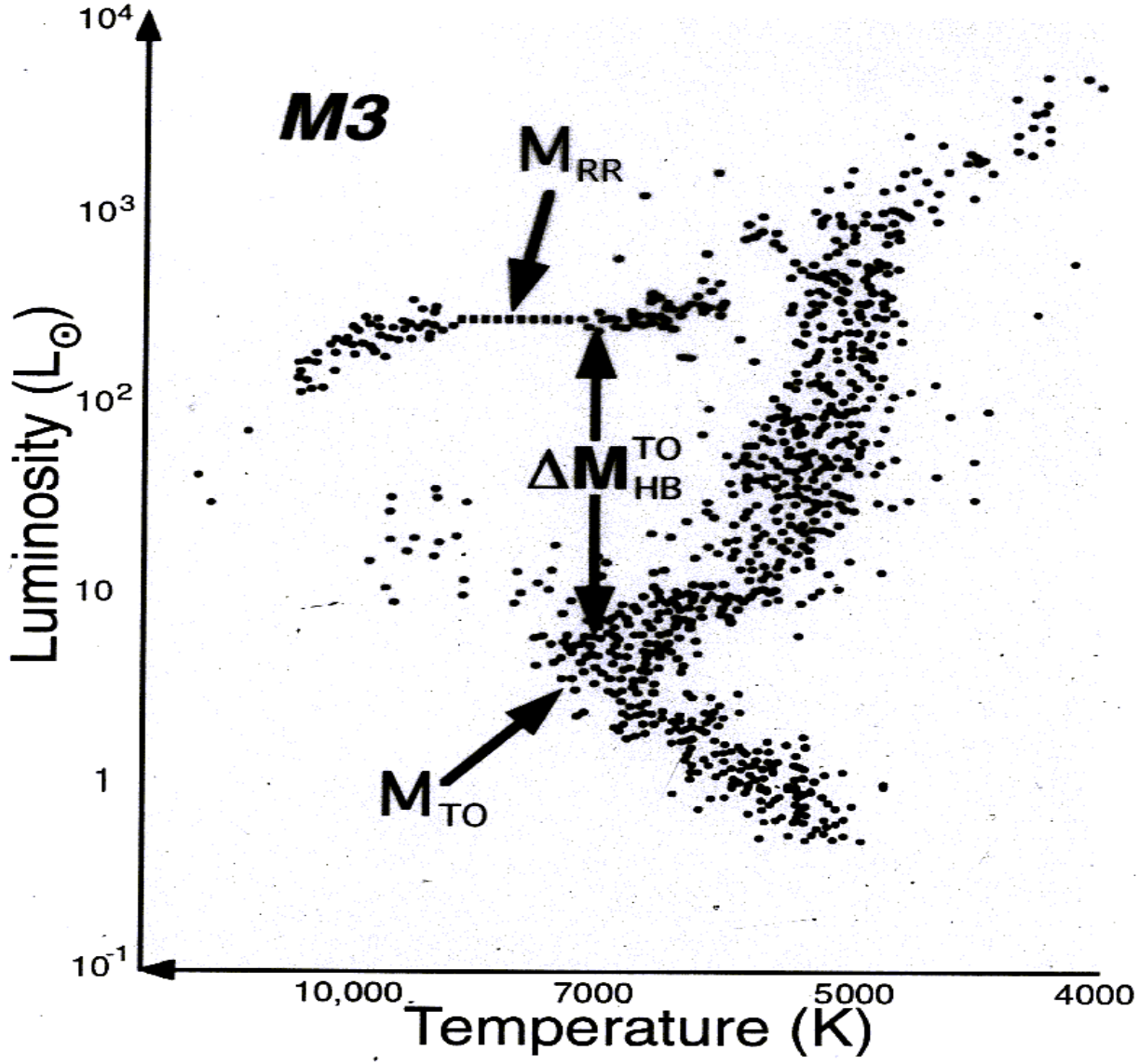


P.F. Bertone
A.E. Champagne
D.C. Powell
C. Iliadis
S.E. Hale
V.Y. Hansper
R.C. Runkle

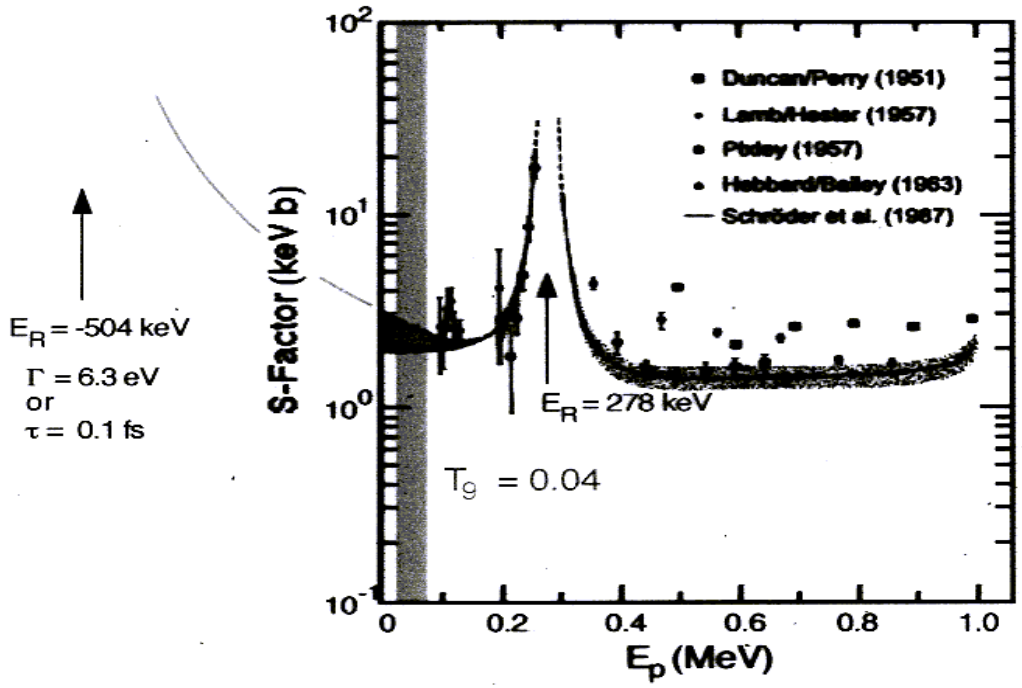

CNO C ES
(p,γ)
(p,α)
^{13}C
^{14}N
^{17}O
^{18}F
β+
^{13}N
^{15}O
^{17}F
β+
(p,γ)
(p,γ)
^{12}C
^{15}N
^{16}O
^{18}O
(p,α)
(p,γ)
(p,α)

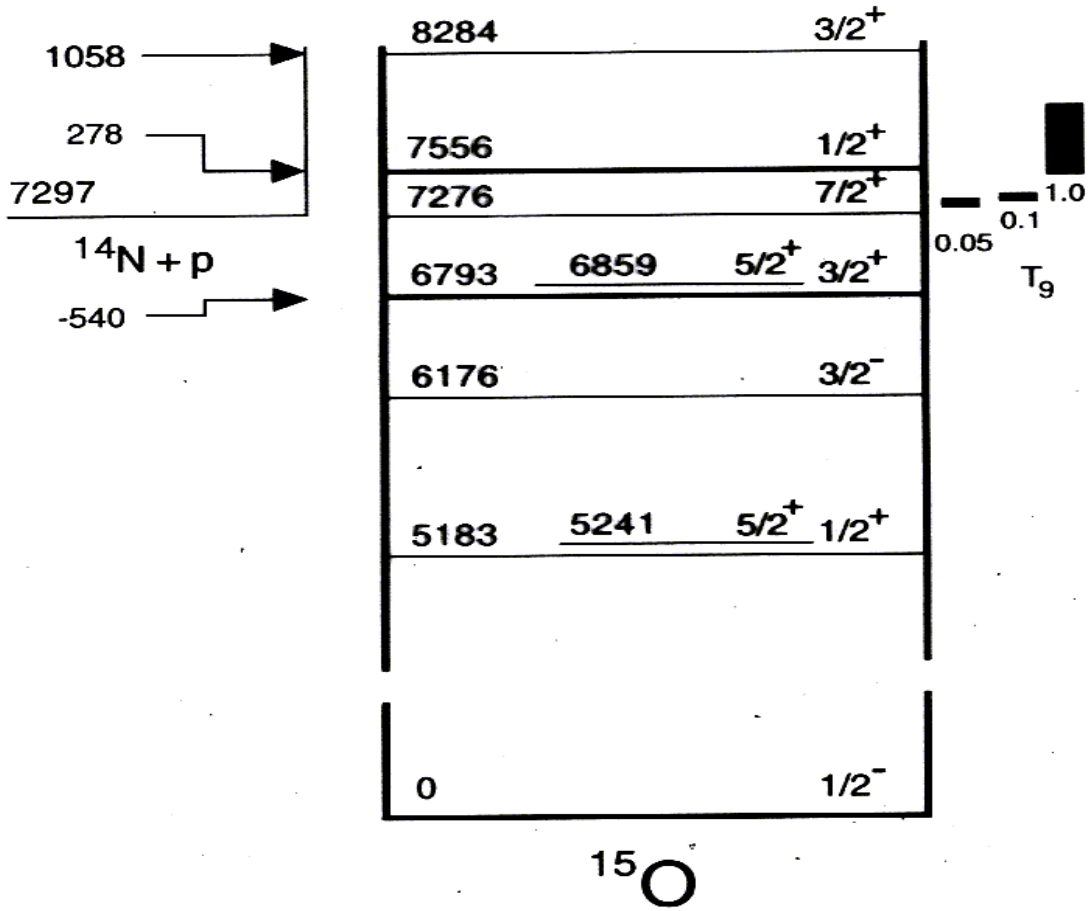

F-supergiants [Barbuy et al., A&A 305, 911 (1996)]
A-supergiants [Venn, Ap. J. 414, 316 (1993)]
CNO equilibrium
$C/N \approx \frac{\lambda_{-14}(\lambda_{-12} + \lambda_{13})}{\lambda_{-12}\lambda_{-13}}$
[C/N]
0
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
0.01
0.1
1
T_9

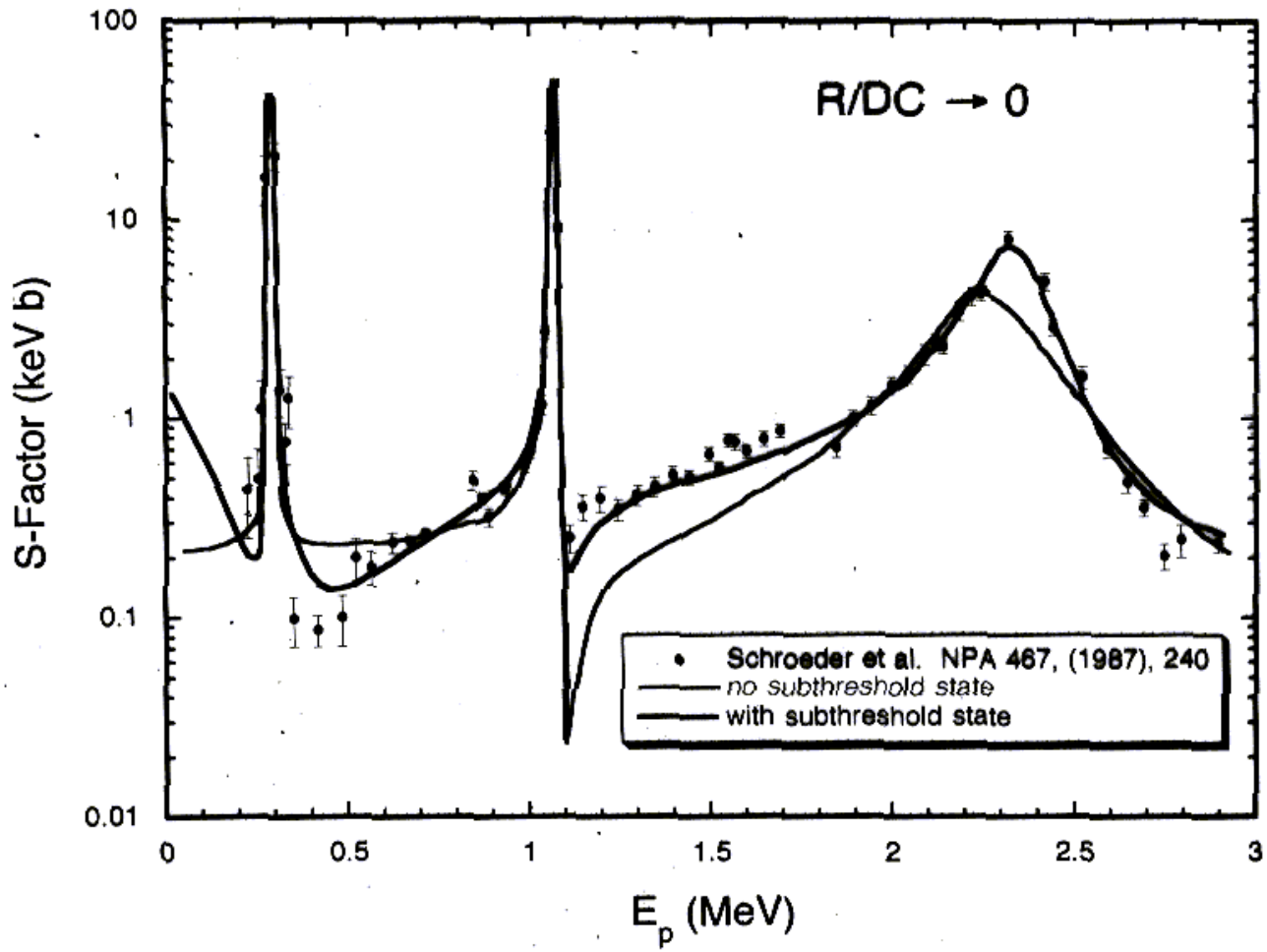
Globular-Cluster Ages:

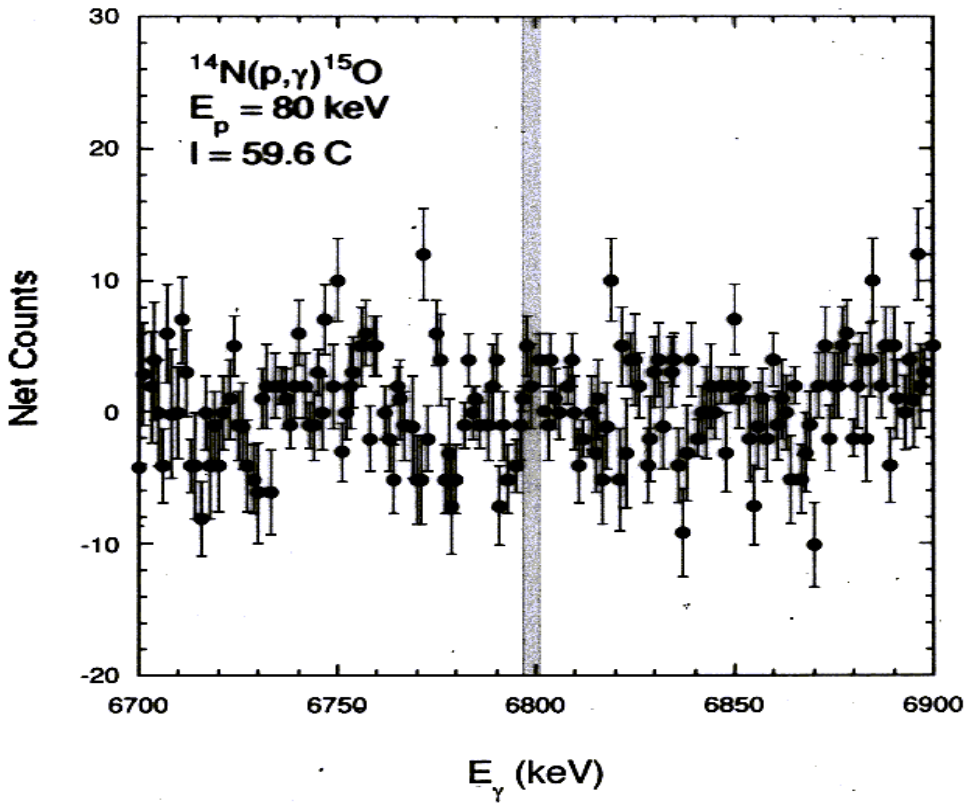


$^{14}N(p,\gamma)^{15}O$




1058
278
7297
14N + p
-540
8284
3/2+
7556
1/2+
7276
7/2+
6793
6859
5/2+
3/2+
6176
3/2−
5183
5241
5/2+
1/2+
0
1/2−
1.0
0.1
0.05
T9
15O


R/DC → 0
S-Factor (keV b)
100
10
1
0.1
0.01
0
0.5
1
1.5
2
2.5
3
E_p (MeV)
Schroeder et al. NPA 467, (1987), 240
no subthreshold state
with subthreshold state


$^{14}N(p,\gamma)^{15}O$
E_p = 80 keV
I = 59.6 C
Net Counts
30
20
10
0
-10
-20
6700
6750
6800
6850
6900
E_γ (keV)

DOPPLER-SHIFT ATTENUATION METHOD:

Doppler shift:

$$E_\gamma = E_\gamma^0 (1 + \beta\cos\theta)$$

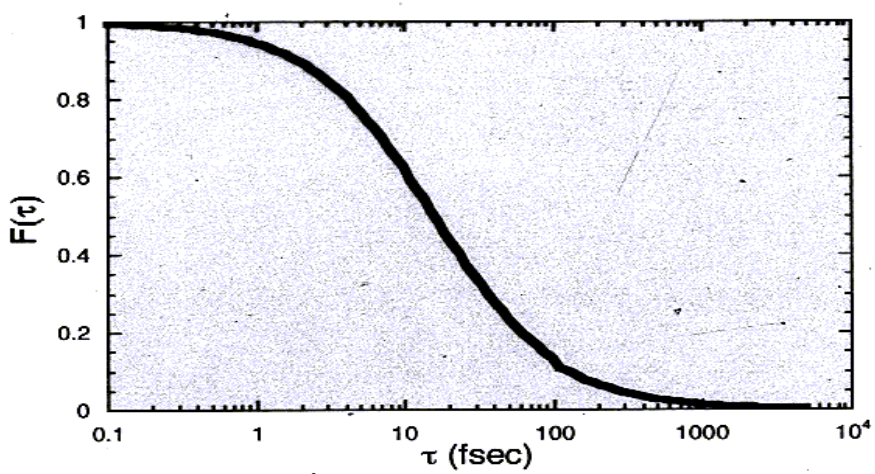
Finite size of detector:

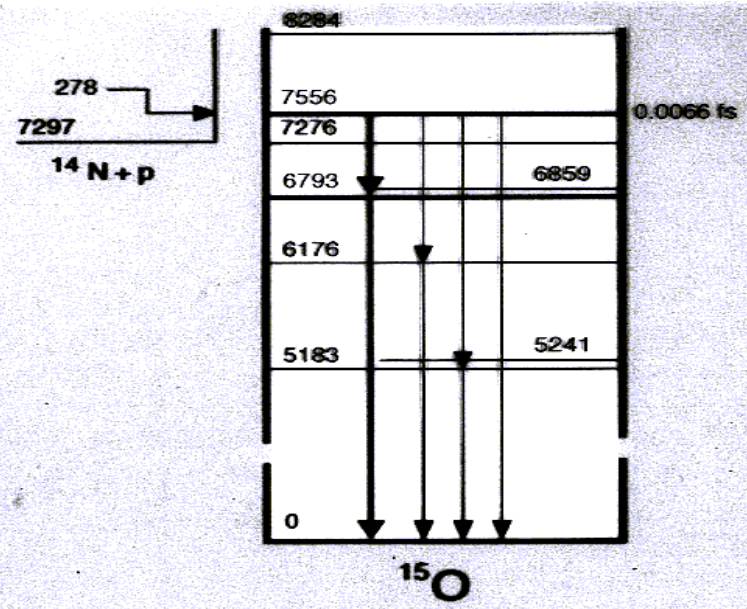
$$E_\gamma = E_\gamma^0 (1 + \beta\, Q\cos\theta)$$

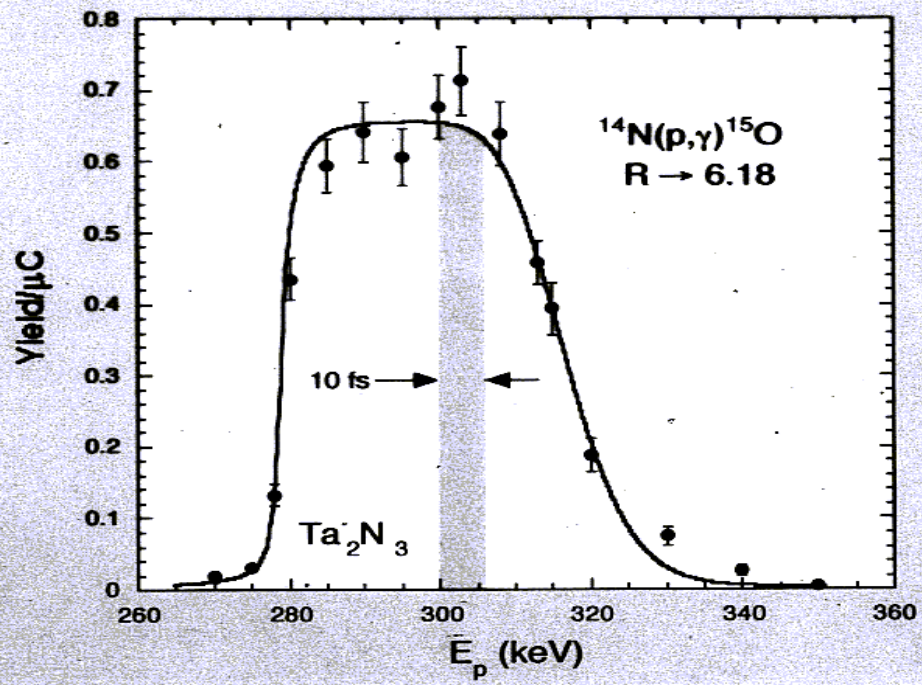
Attenuation from energy loss in target:

$$E_\gamma = E_\gamma^0 [1 + \beta\ \ F(\tau)\, Q\cos\theta],,$$

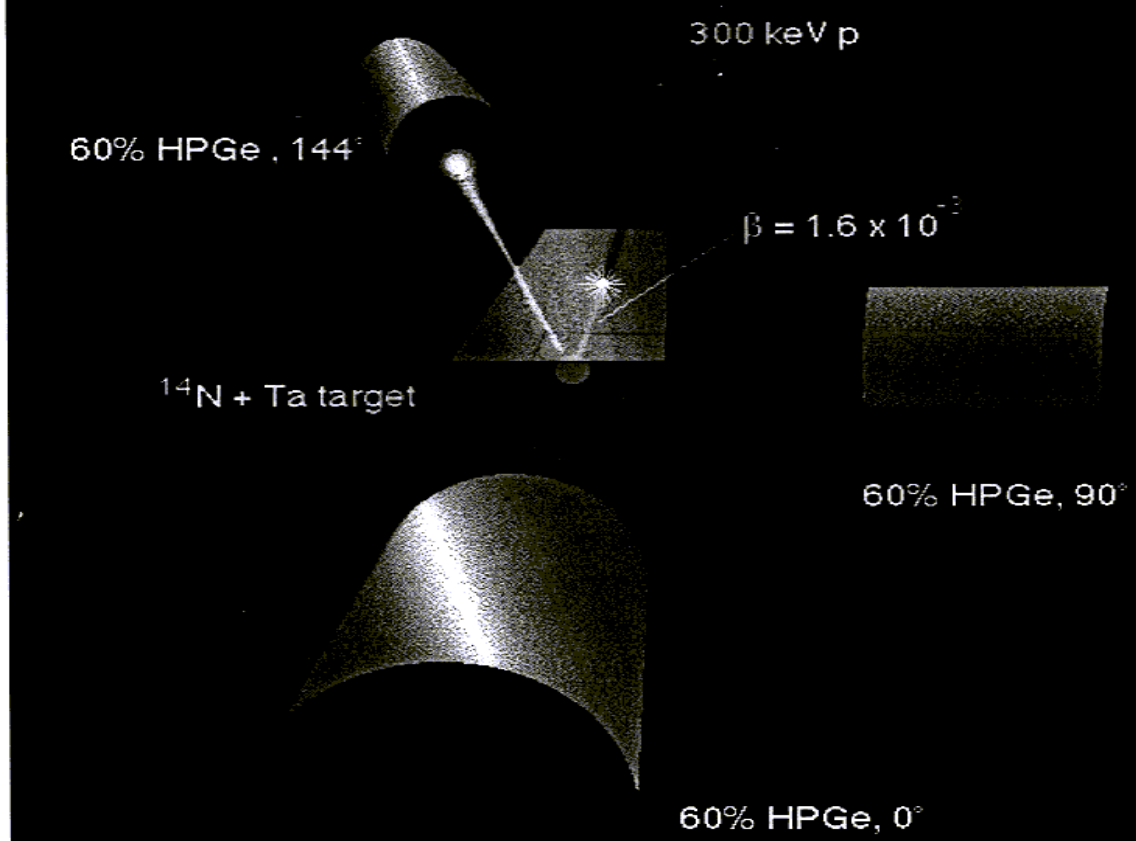
$$F(\tau) = \frac{\int_0^\infty e^{-t/\tau}\, \overline{v(t)\cos\phi}\ dt}{v_0 \tau}$$



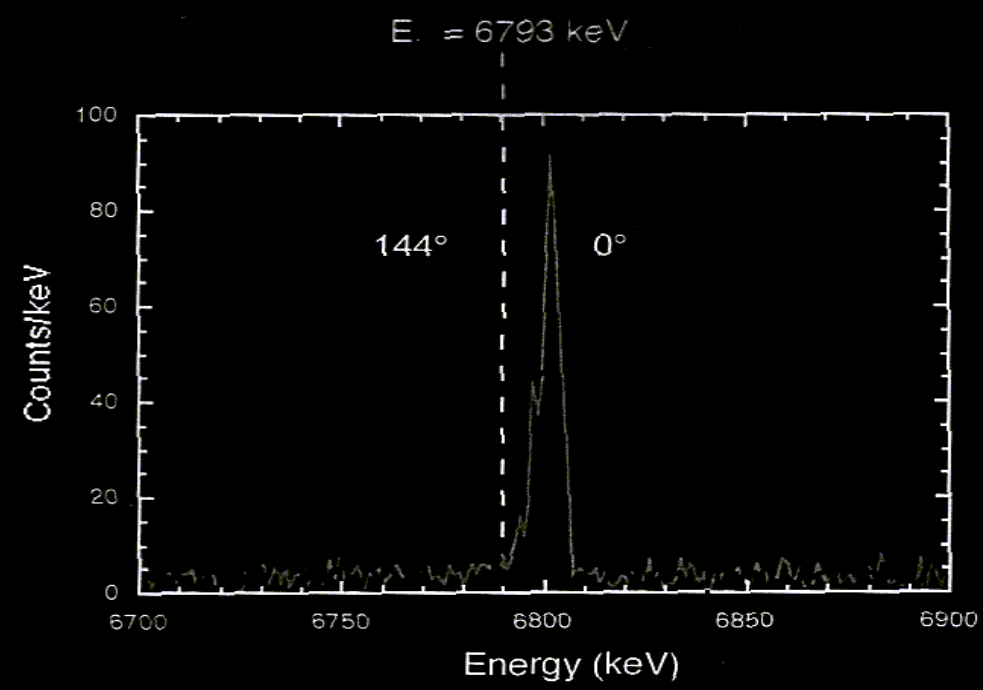

8284
278
7297
^{14}N+p
7556
7276
6793
6859
6176
5183
5241
0
0.0066 fs
^{15}O


^{14}N(p,γ)^{15}O
R → 6.18
10 fs
Ta$_2$N$_3$
Yield/μC
E_p (keV)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
260
280
300
320
340
360

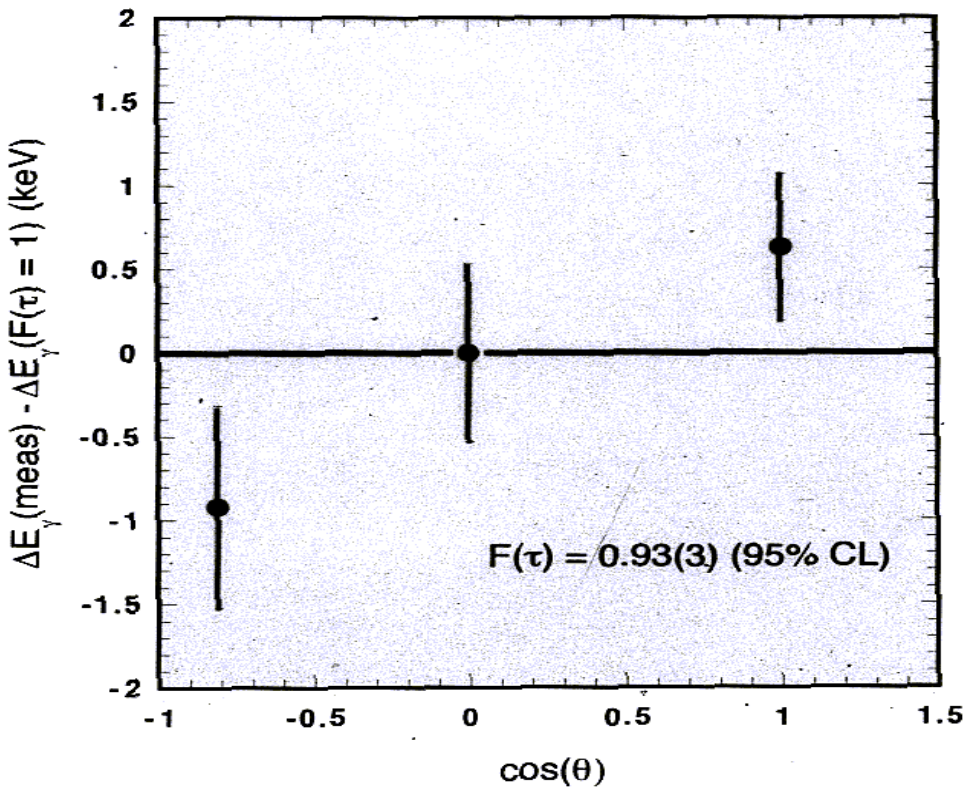
Setup for Lifetime Measurement



$^{14}N(p,\gamma)^{15}O(7556) \rightarrow {}^{15}O(6793) \rightarrow {}^{15}O(ground)$



$$F(\tau) = \frac{\Delta E_\gamma}{E_\gamma^0 \; \beta_0 \, Q \cos\theta}$$


2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-1
-0.5
0
0.5
1
1.5
ΔE_γ(meas) - ΔE_γ(F(τ) = 1) (keV)
cos(θ)
F(τ) = 0.93(3) (95% CL)

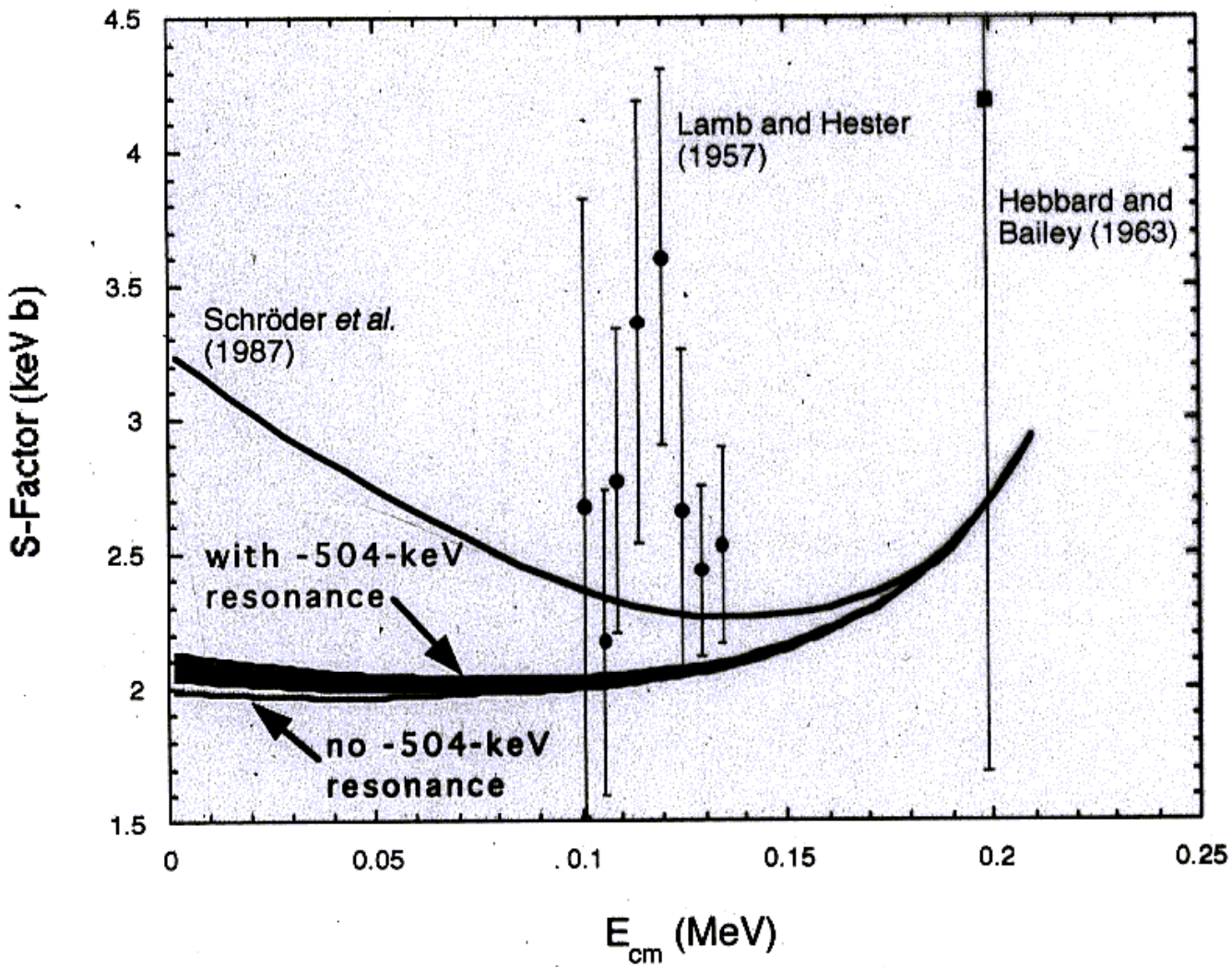
RESULTS

E_x (keV)	$F(\tau)$ (95% cl)	Lifetime (fs, 95% cl)		B_L	
		present	literature	^{15}O	^{15}N
5183	0.68(3)	$9.67^{+1.34}_{-1.24}$	8.2(20)	4.67×10^{-4}	1.69×10^{-4}
6176	0.91(5)	$2.10^{+1.33}_{-1.22}$	≤ 2.5	0.11	0.66?
6793	0.93(3)	$1.60^{+0.75}_{-0.72}$	≤28, 0.1	1.25×10^{-3}	2.64×10^{-3}

Systematic uncertainties in τ:

- target composition ±7.5%
- nuclear stopping ±5.1%
- electronic stopping ≤ 3.0%
- width of feeding state ±7.1%
- angular spread of recoils ±1.0%

$^{14}N(p,\gamma)^{15}O$ S-Factor



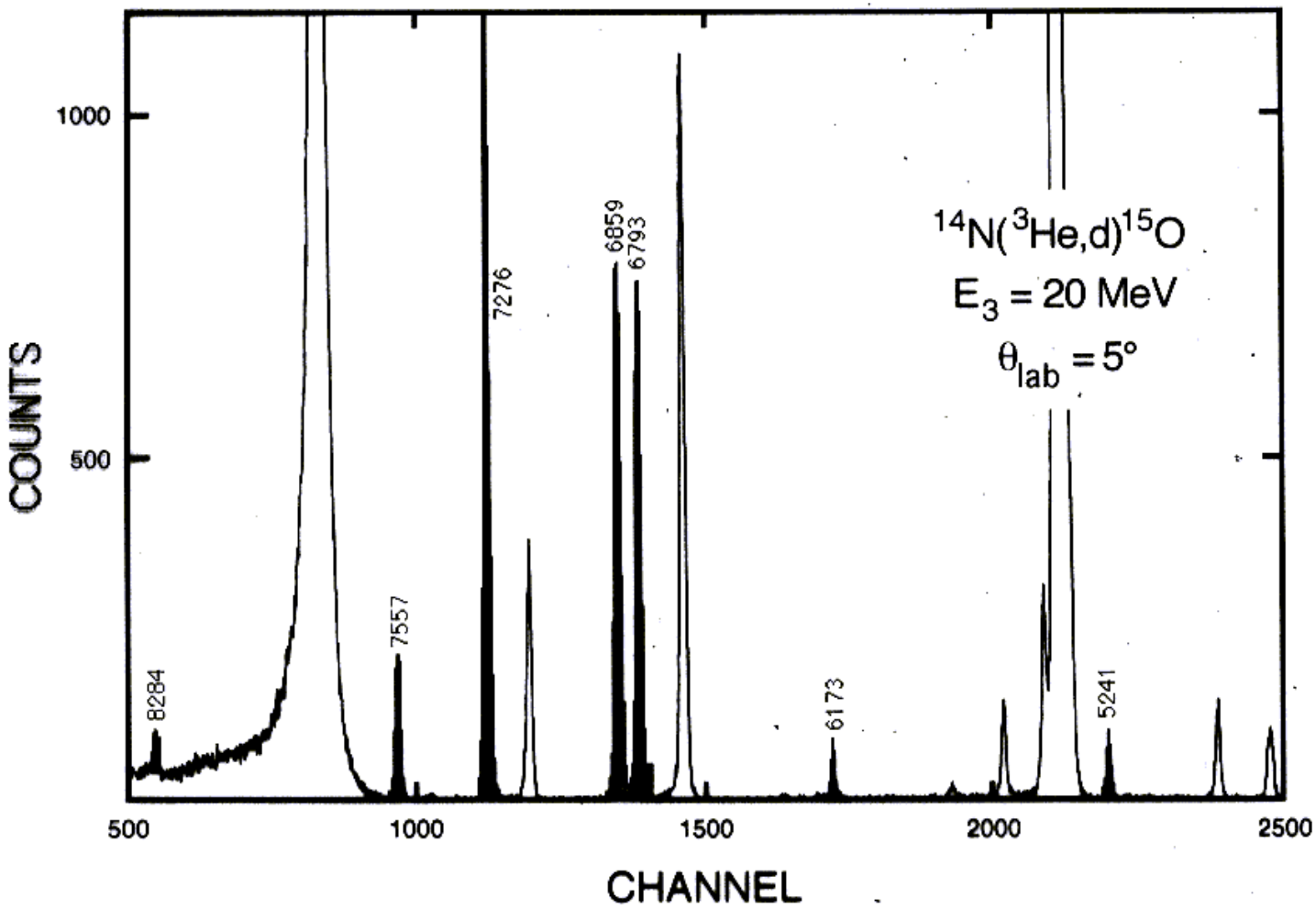
CONSEQUENCES:

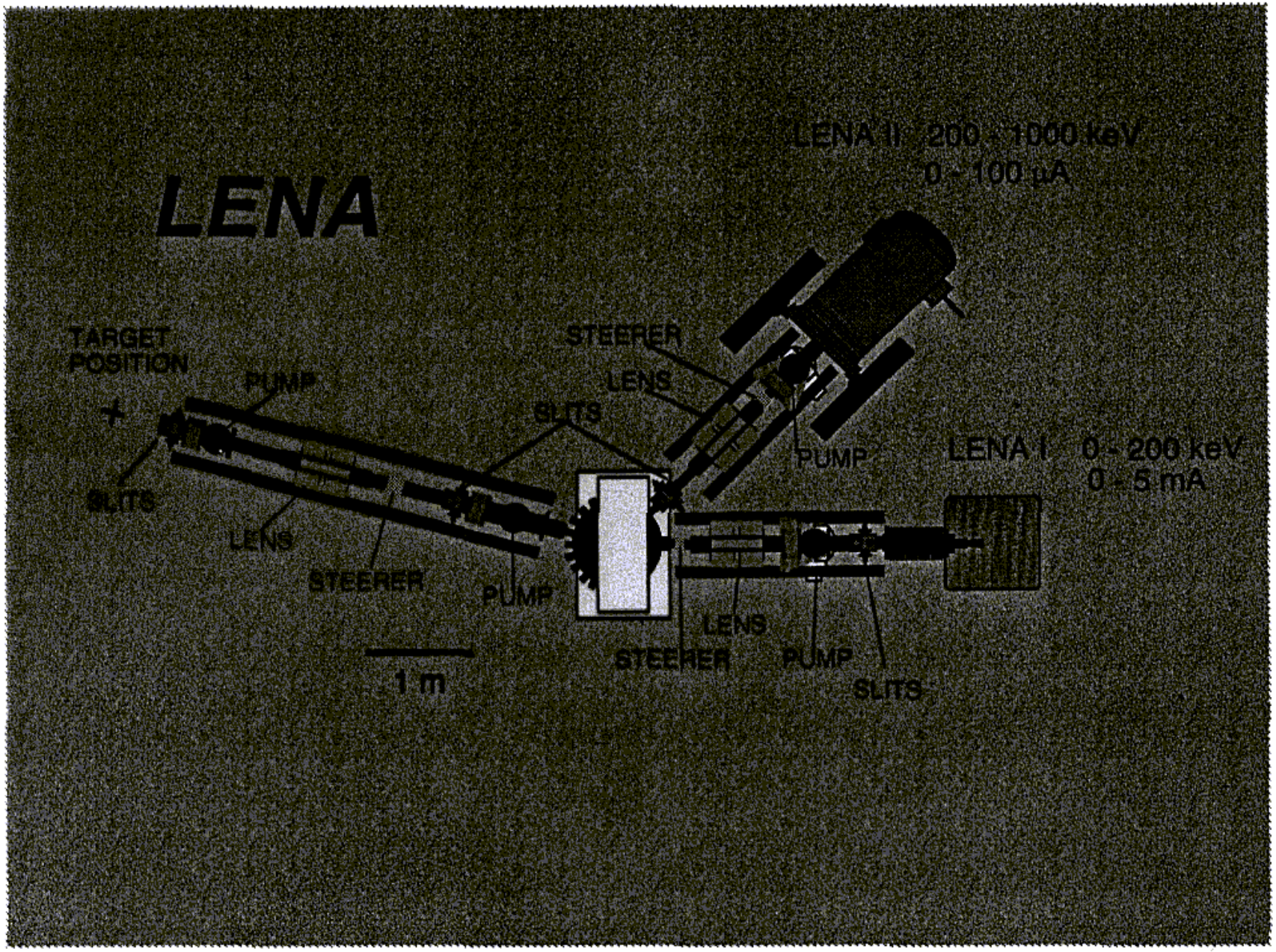
1. S(E) is reduced by $\leq$ 36% for E $\leq$ 180 keV

2. Equilibrium C/N reduced by 30 - 20% (0.16 - 0.1 dex) for T_9 = 0.01 - 0.1

3. Cluster ages derived from M_{TO} **increase** by 5% from 11.5(13) Gy (B. Chaboyer)

   Ages derived from ΔM_{HB}^{TO} **decrease** by ~11%


$^{14}N(^{3}He,d)^{15}O$
$E_3 = 20$ MeV
$\theta_{lab} = 5°$
8284
7557
7276
6859
6793
6173
5241
COUNTS
CHANNEL
500
1000
1500
2000
2500


LENA
LENA II 200 - 1000 keV
0 - 100 μA
TARGET
POSITION
PUMP
SLITS
LENS
STEERER
PUMP
SLITS
STEERER
LENS
PUMP
LENA I 0 - 200 keV
0 - 5 mA
LENS
STEERER
PUMP
SLITS
1 m