Continuum shell model calculations for nucleon capture at astrophysical energies

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H burning
pp chain

<E>=0.27MeV

$p(p,e^+\nu)d$

99.75%

<E>=1.44MeV

$p(e^-p,\ \nu)d$

0.25%

$d(p,\gamma)^3He$

86%

$^3He(3He,2p)^4He$

14%

$^3He(\alpha,\gamma)^7Be$

$2 \cdot 10^{-5}\%$

$^3He(p,e^+\nu)^4He$

99.89%

$^7Be(e^-,\nu)^7Li$

$^7Li(p,\ \alpha)^4He$

<E>=0.39,0.86MeV

0.11%

<E>=6.8 MeV

$^7Be(p,\gamma)^8B$

$^8B(e^+\nu)^8Be$

$^8Be(\alpha)^4He$

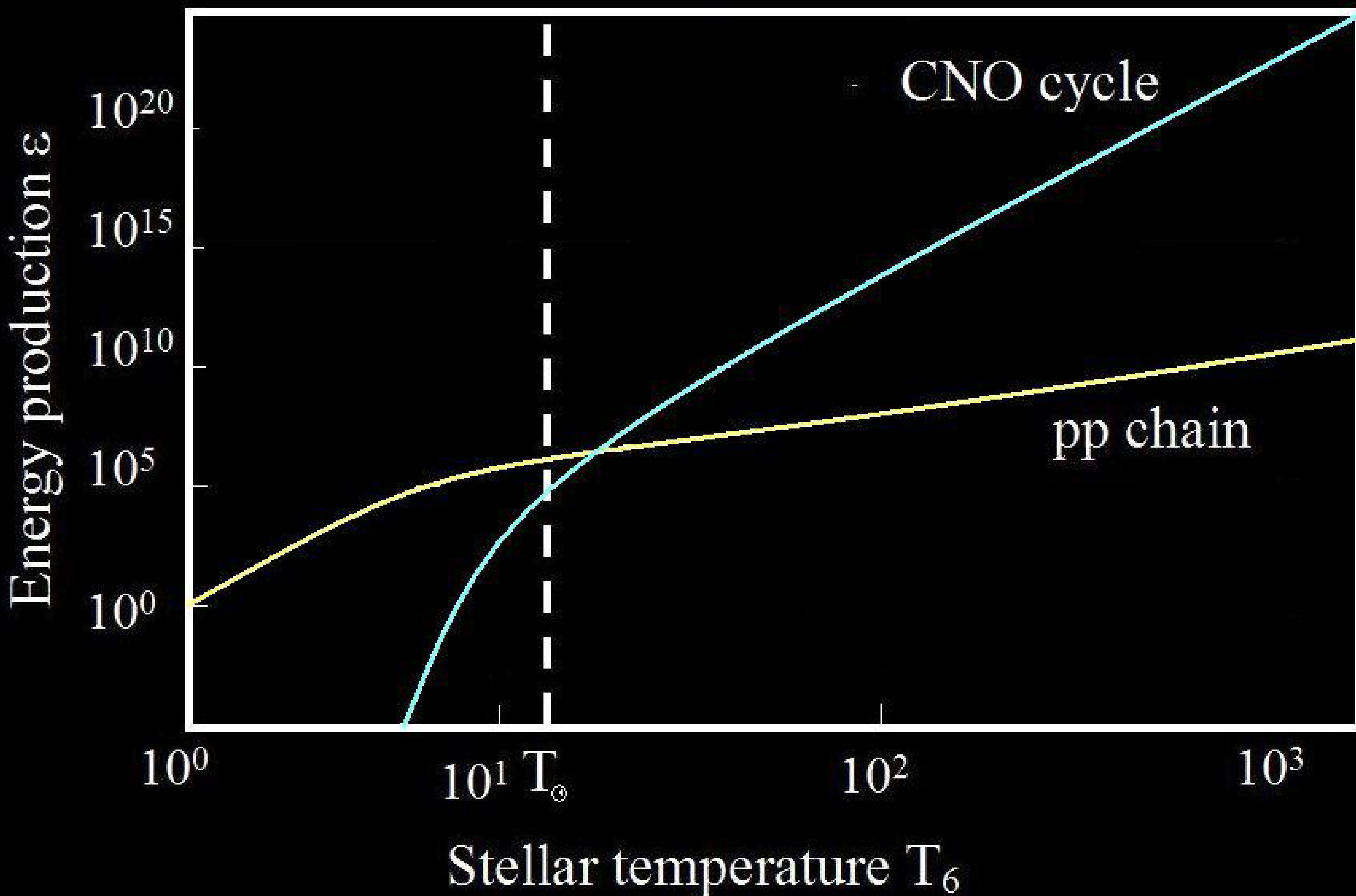
$^{7}Be(p,\gamma)^{8}B$

Production rate of ^{8}Be solar neutrinos:

- accuracy of stellar models
- neutrino mixing and nature of weak interaction

desired reaction rate uncertainty less than 5%

Dependance on temperature of energy production rates



CNO cycle

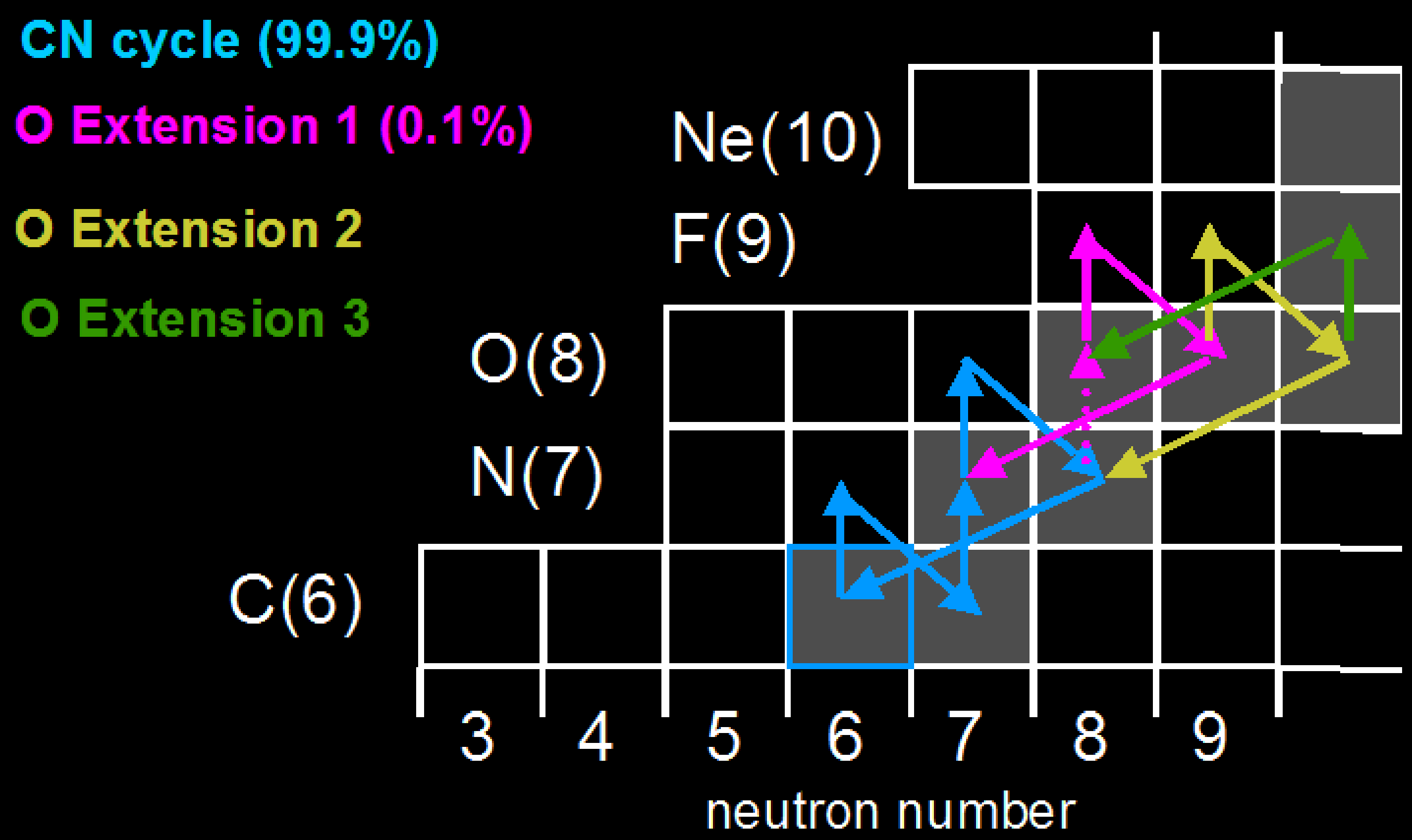


figure taken from H. Schatz (2004)

4 CNO cycles

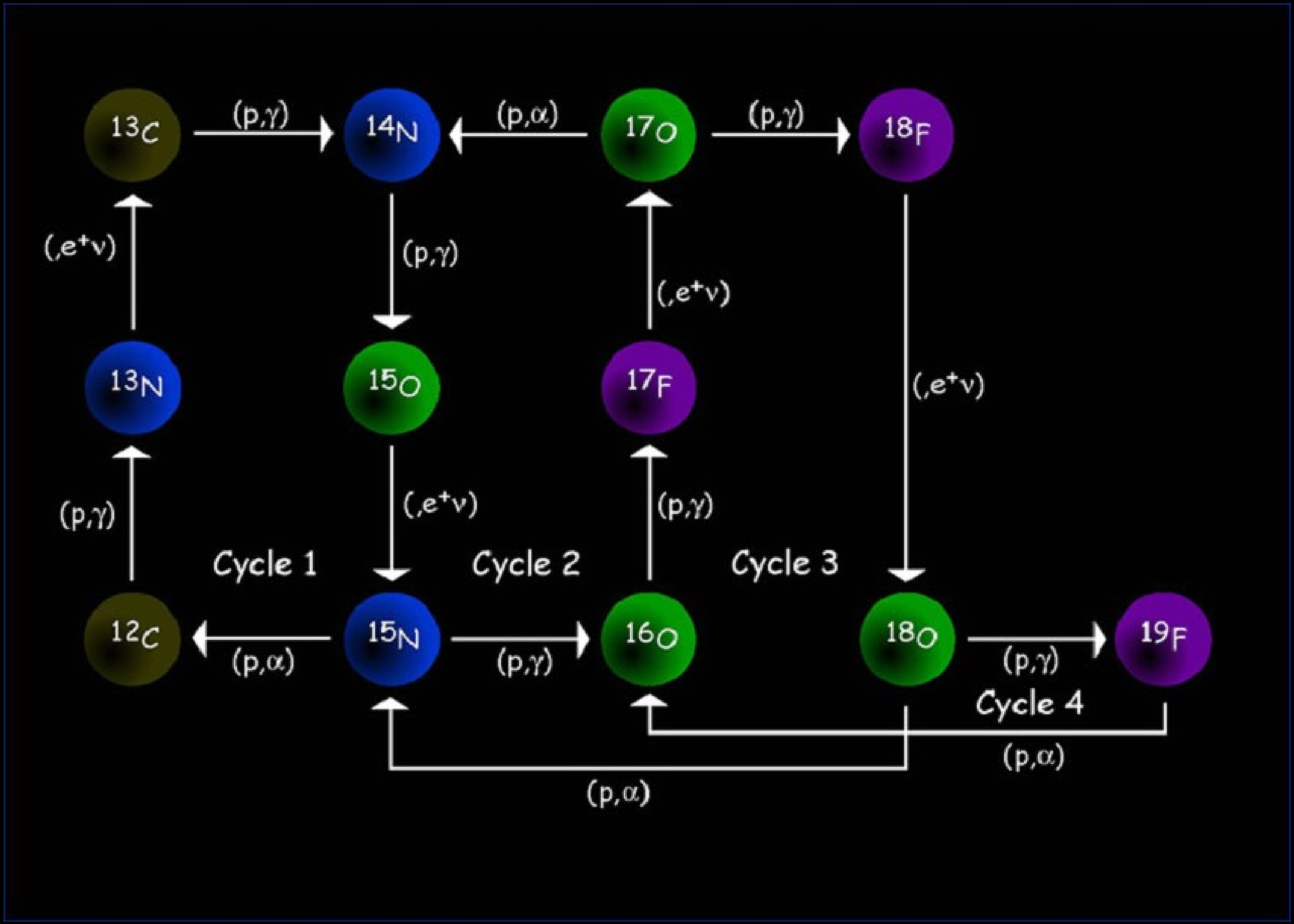


figure taken from H. Schatz (2004)

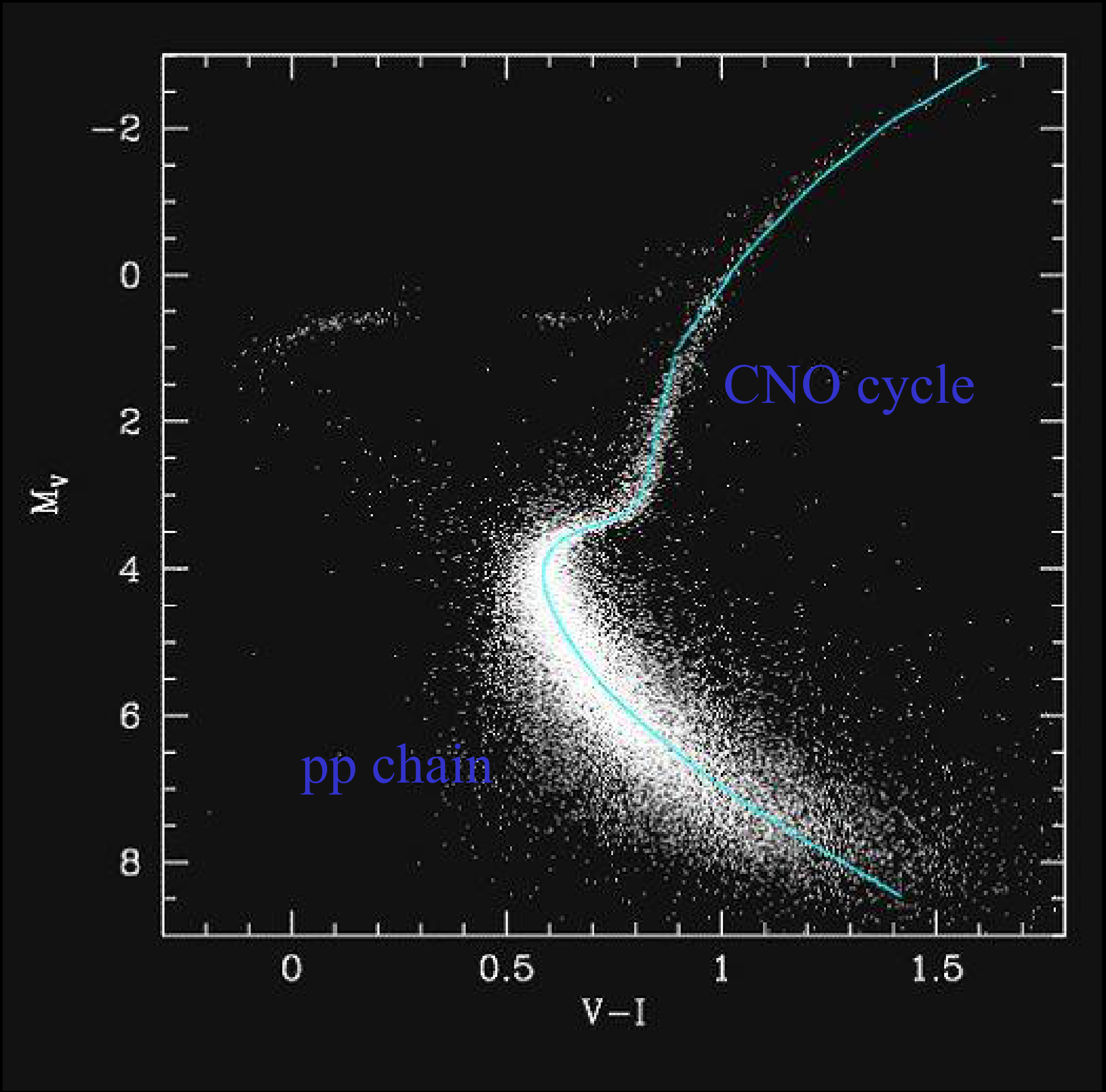
$^{14}N(p,\gamma)^{15}O$

Slowest reaction in CNO cycle

- controls duration of hydrogen burning
- determines main sequence turnoff – globular cluster ages
- determines CNO neutrino flux in the Sun

Initial abundance of C, N,O is mostly converted into ^{14}N

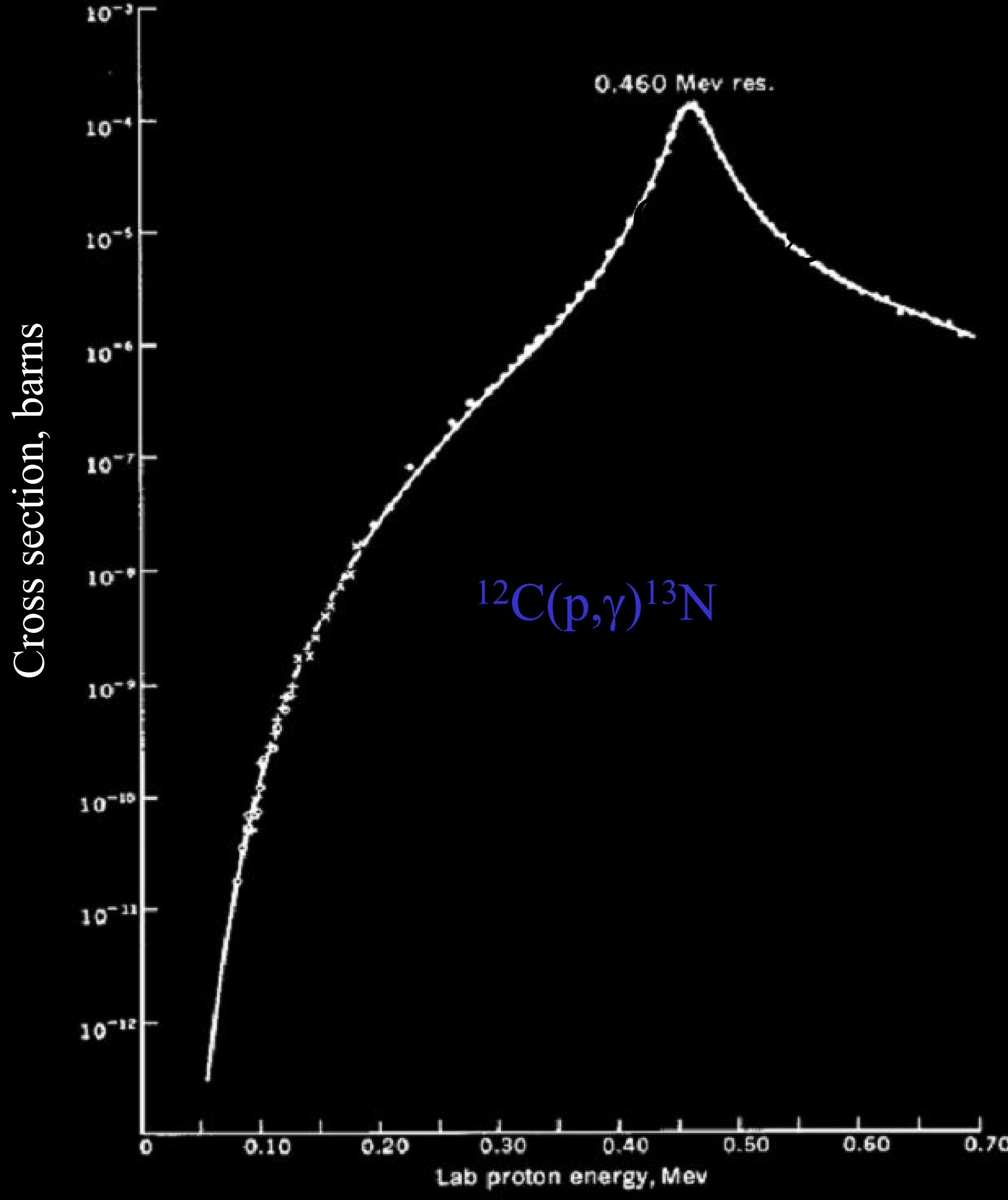
Turn off luminosity – age of globular clusters



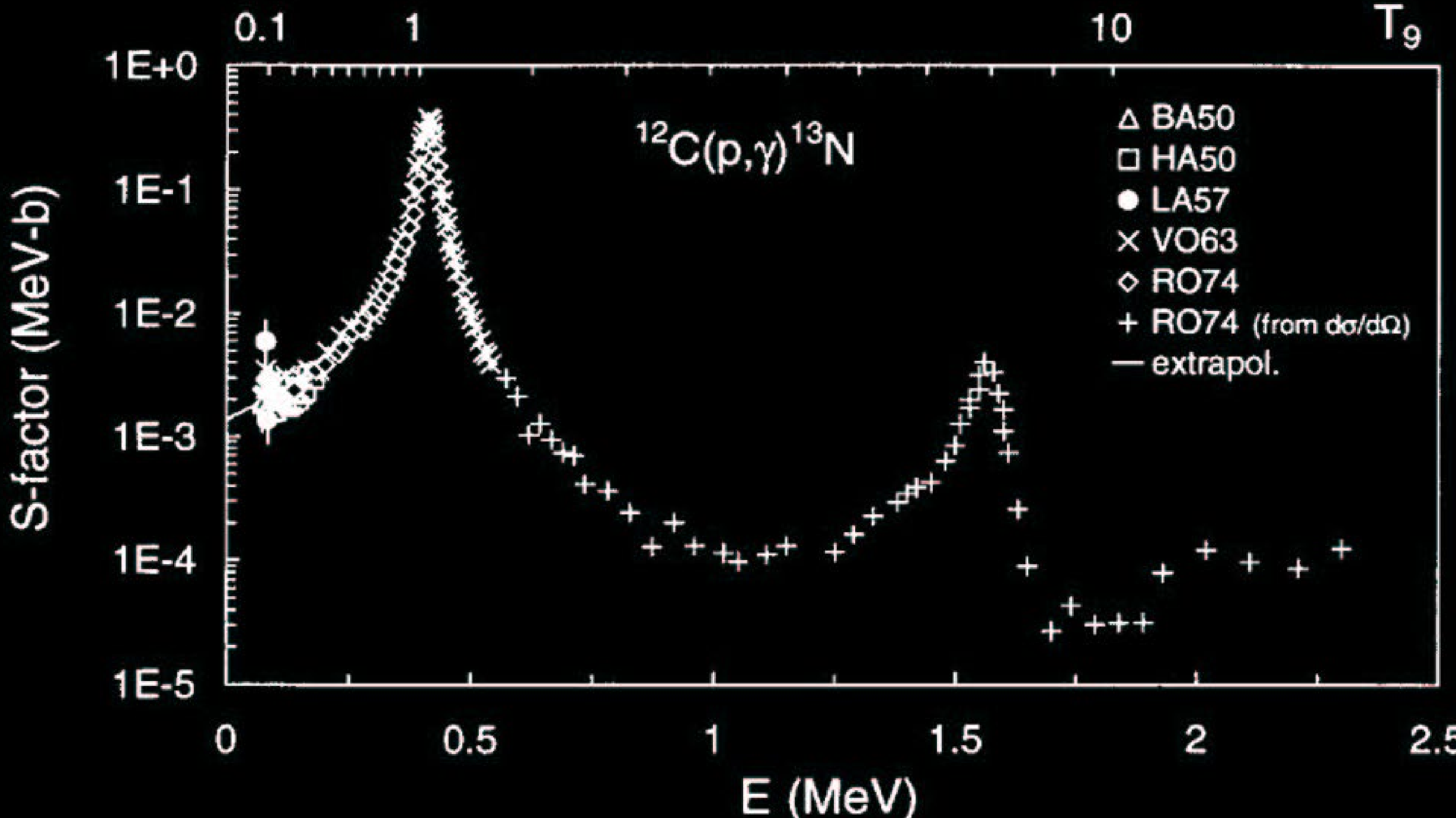
Proton capture reactions

Crossections are extremely low $\Rightarrow$

measure as low in energy as possible, then extrapolate to Gamow window



Cross section, barns
0.460 Mev res.
$^{12}C(p,\gamma)^{13}N$
Lab proton energy, Mev
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
0
0.10
0.20
0.30
0.40
0.50
0.60
0.70

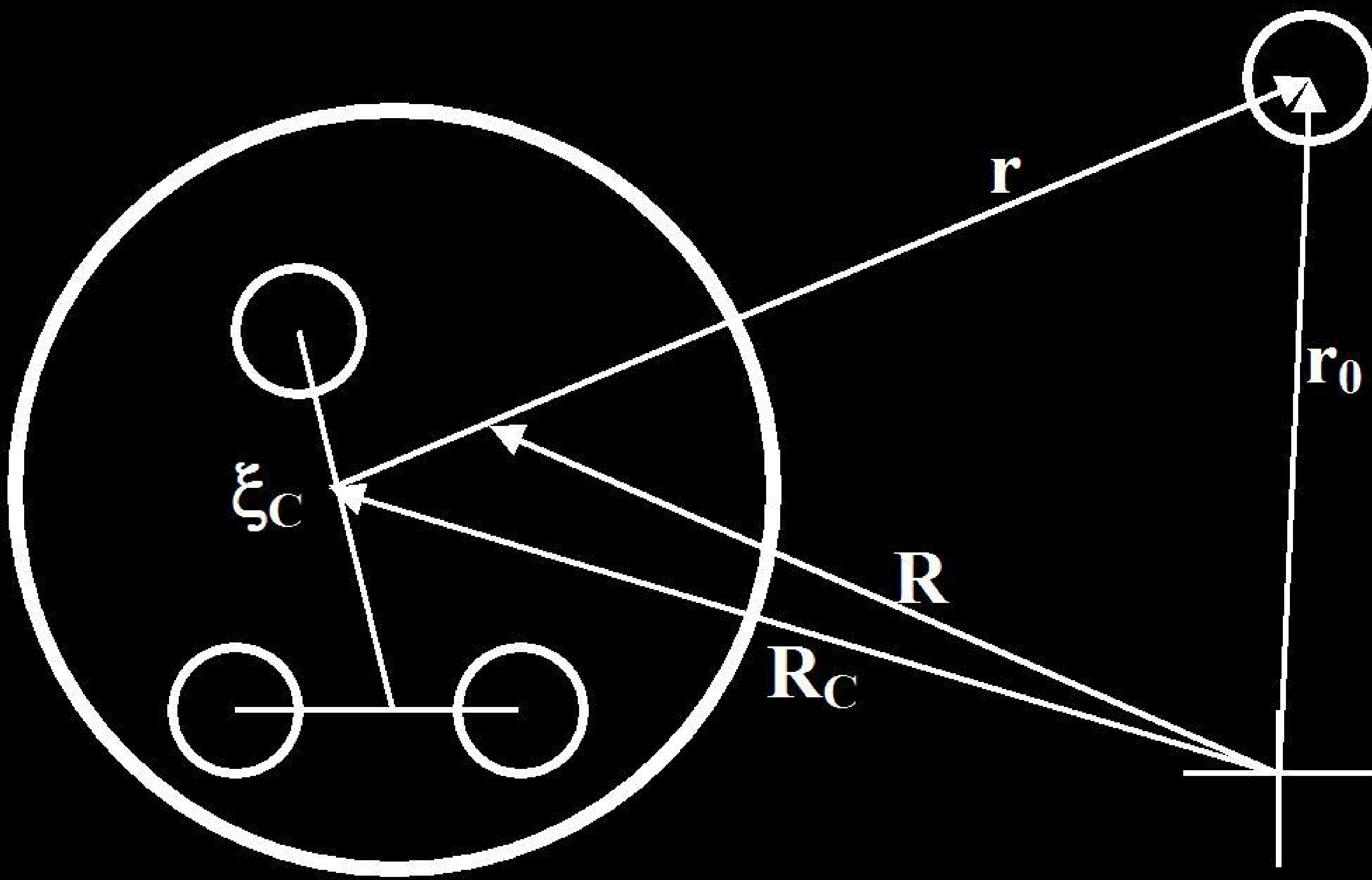


0.1
1
10
T_9
1E+0
1E-1
1E-2
1E-3
1E-4
1E-5
$^{12}C(p,\gamma)^{13}N$
△ BA50
□ HA50
● LA57
× VO63
◇ RO74
+ RO74 (from dσ/dΩ)
— extrapol.
S-factor (MeV-b)
0
0.5
1
1.5
2
2.5
E (MeV)

RCCSM advantages R.J.Phillpott

- Provides coupled-channels solutions for bound and unbound wave functions
- Wave functions antisymmetric and contain no spurious components
- Bound states and continuum states are orthogonal

RCCSM coordinates



RCCSM input

- Oscillator size parameter ν_0=mw/ħ
- Desired states of the A-1 core nuclei
- Realistic translationally invariant interaction

Interaction

- A fit to Cohen-Kurath interaction and Reid soft core g-matrix elements
- Spin orbit force
- Tensor force
- Skyrme interaction

Channel wave functions within channel radius a_c

$$\Psi_{J_B} = \sum_{J_A \alpha \bar{l} \bar{j} \bar{n} \neq 0} f_{\bar{n}\bar{l}\bar{j} J_A \alpha J_B} \left[a^{+}_{\bar{n}\bar{l}\bar{j}} \otimes \left| \alpha J_A \right\rangle \right]^{J_B} + \sum_{\beta} d_{\beta} \left| \beta J_B \right\rangle$$

Calculations

- Oscillator size parameter, interaction
- R matrix radii
- Calculate matrix elements of interaction
- CM transformation
- R matrix techniques to get f and d coefficients

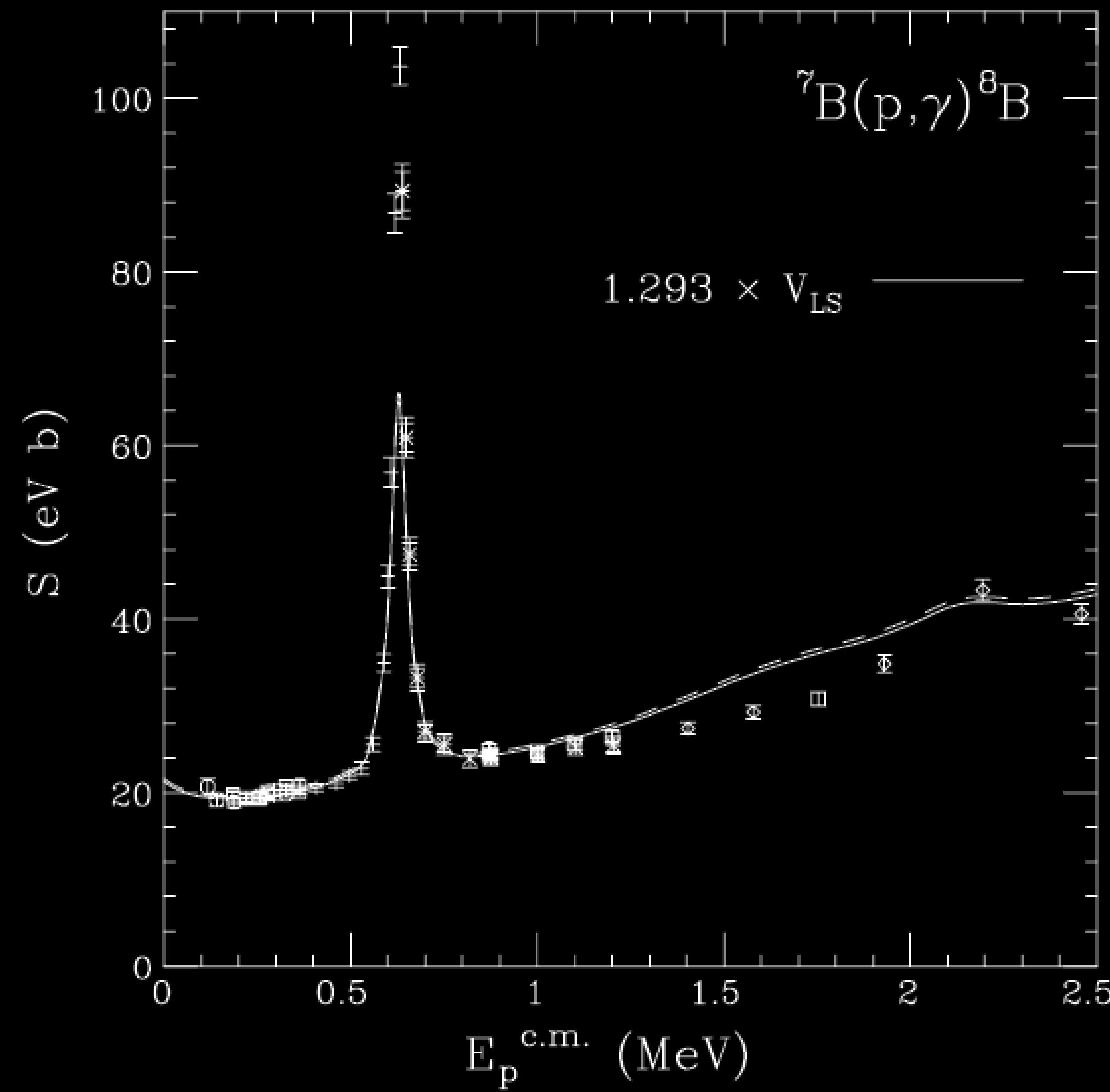
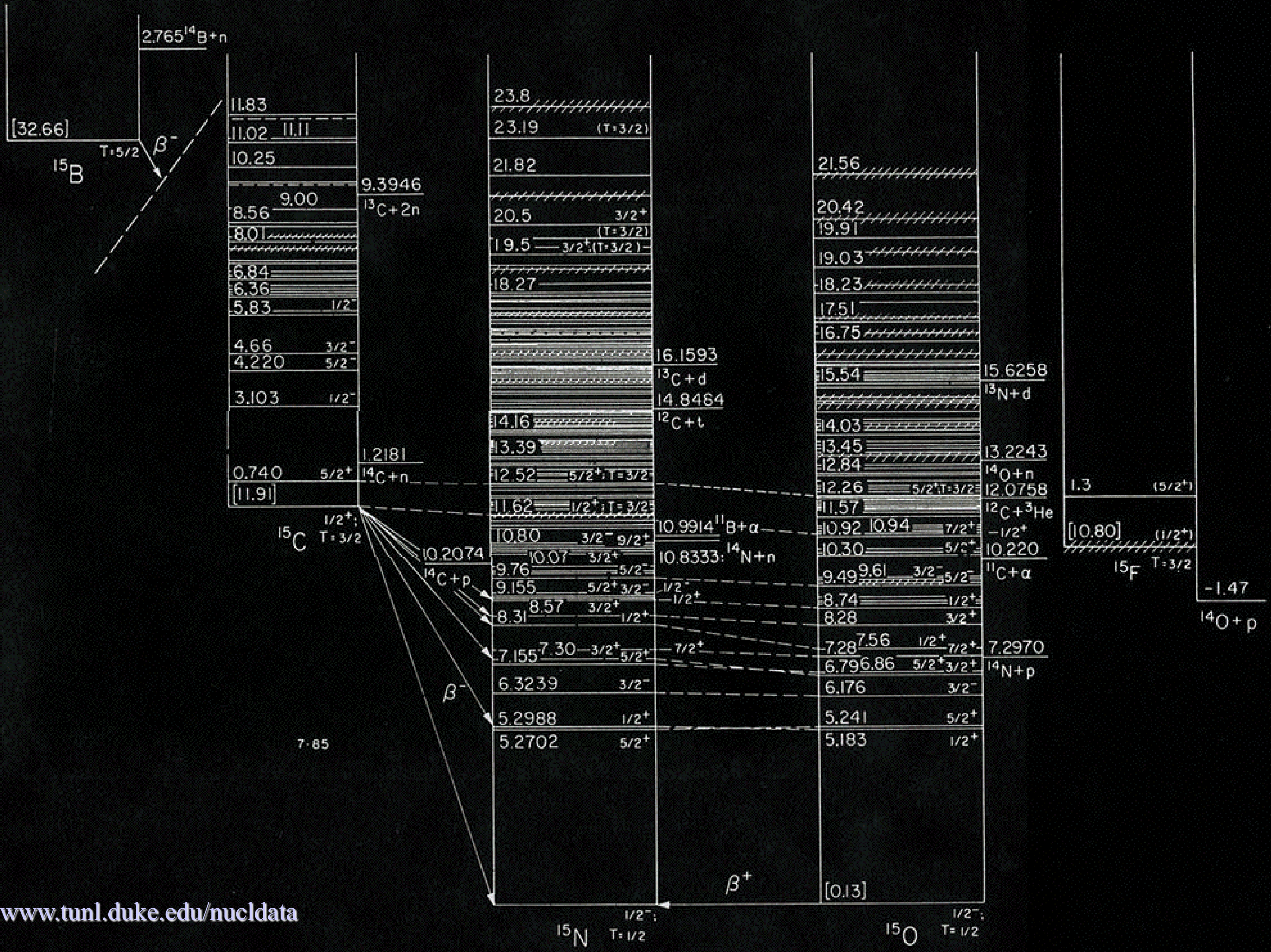


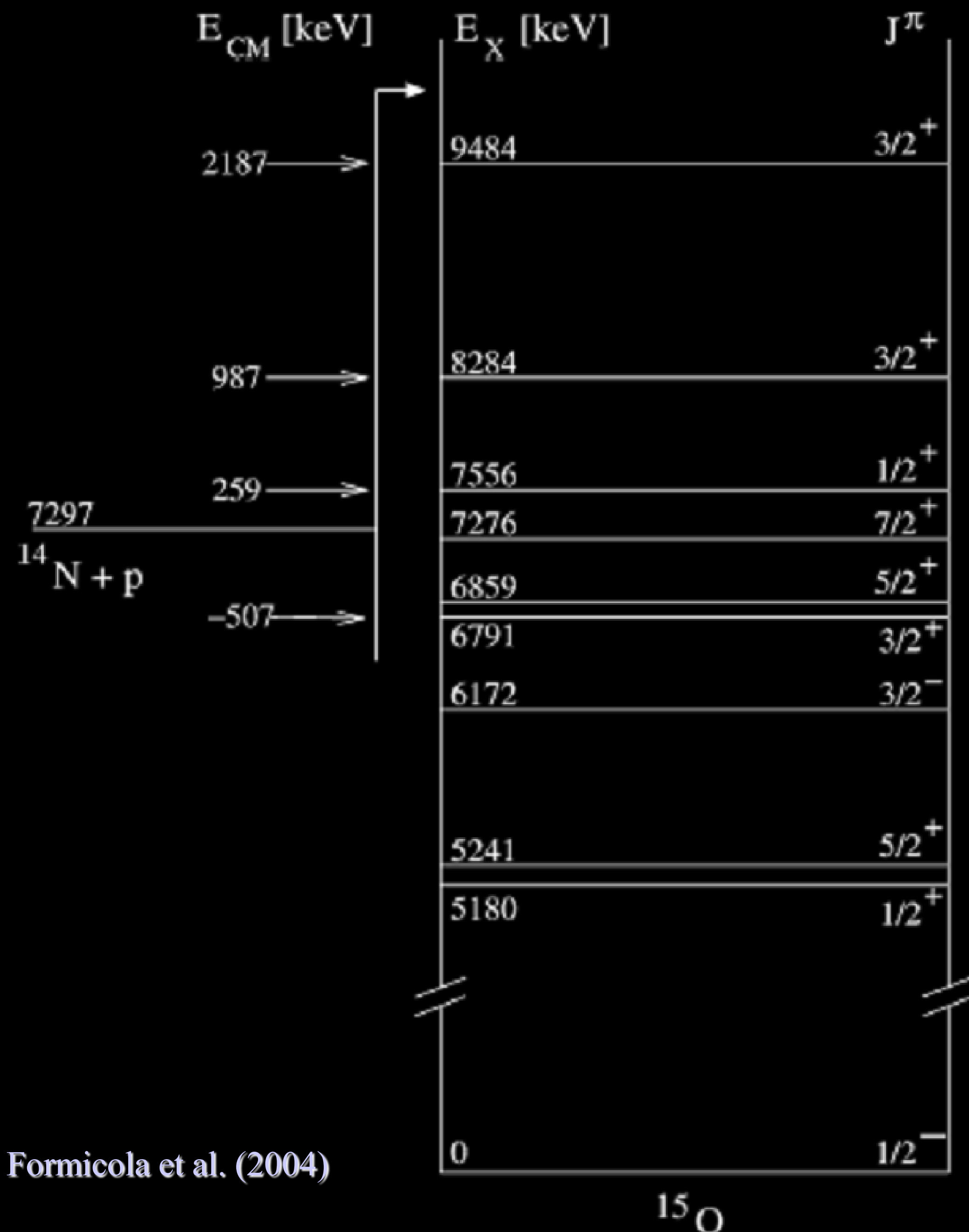
FIG. 5. S factor for $^7Be(p,\gamma)^8B$. Line is $1.293 \times V_{LS}$ calculation with $E1$ contribution scaled by 0.726. Circles, ×'s, squares, and diamonds are BE3L, BE1, BE3S, and BE2 data from Ref. [1].

Dean Halderson (2006)



www.tunl.duke.edu/nucldata

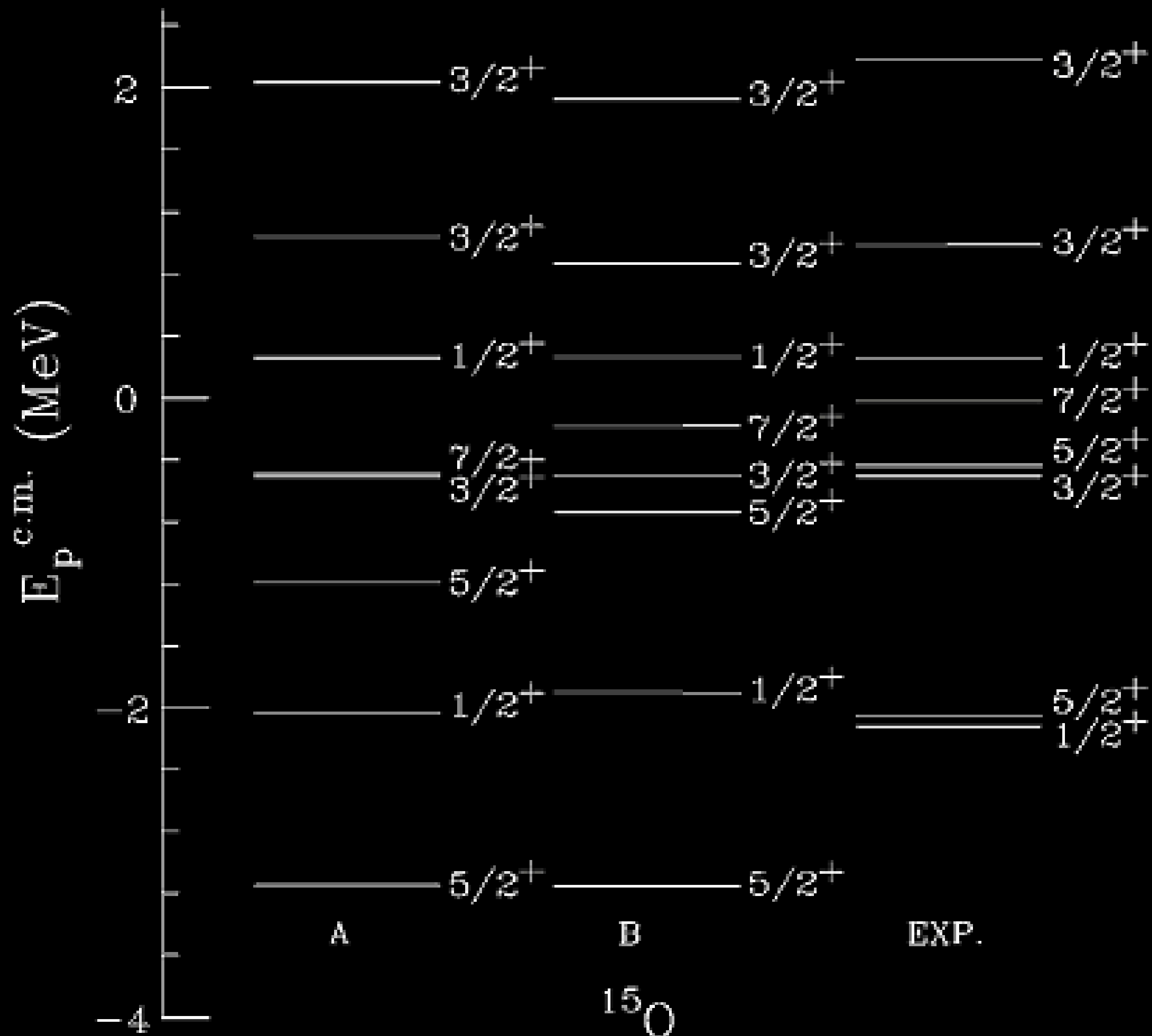
$^{14}N(p, \gamma)$ level scheme



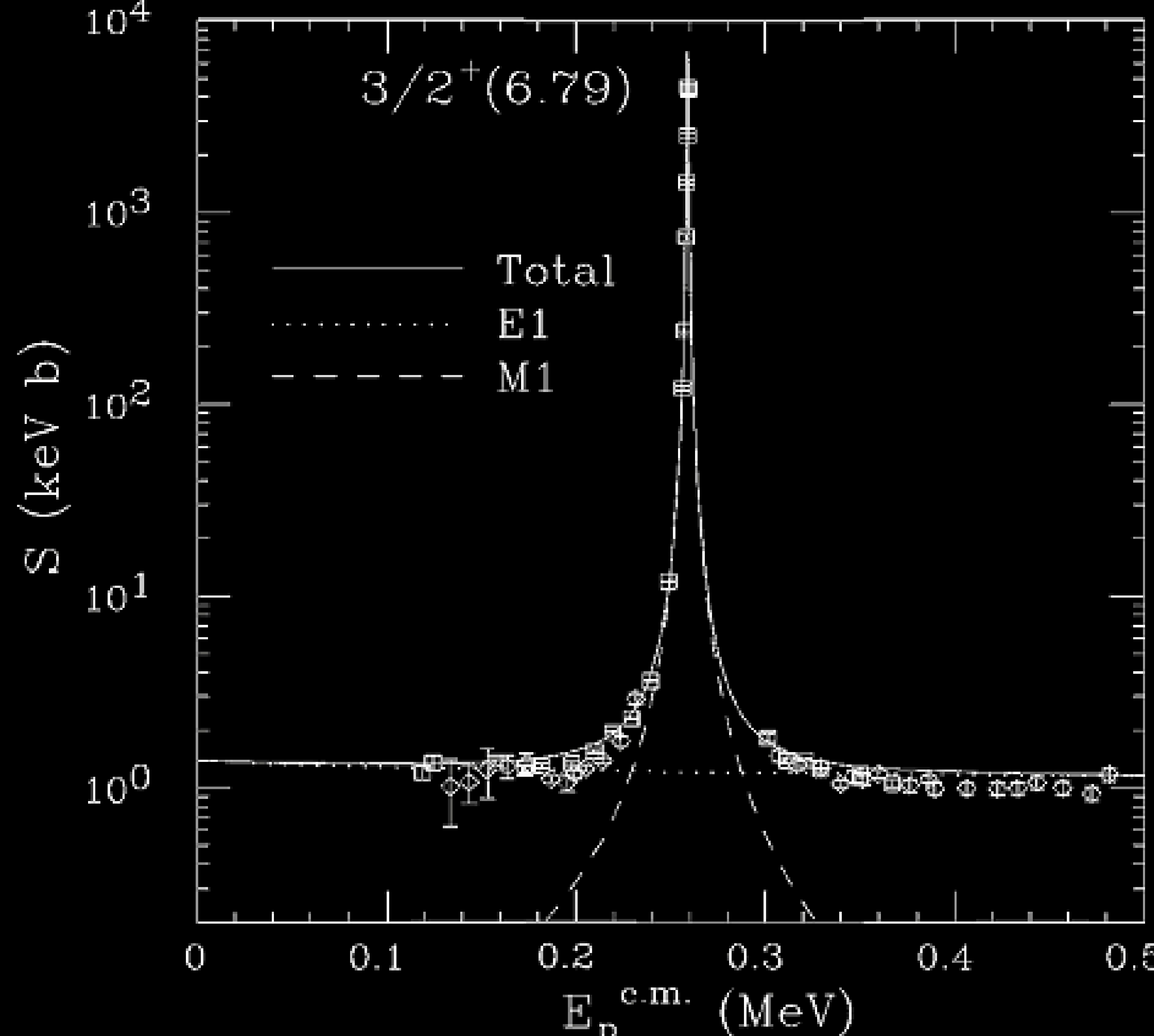
Gamow peak at 26.5 keV
for T_6=15

figure taken from A. Formicola et al. (2004)

The ^{15}O positive parity spectrum



S factor for the transition to the $3/2^+$ (6.79MeV) state in ^{15}O



$1/2^+_2 \rightarrow 1/2^-$ transition

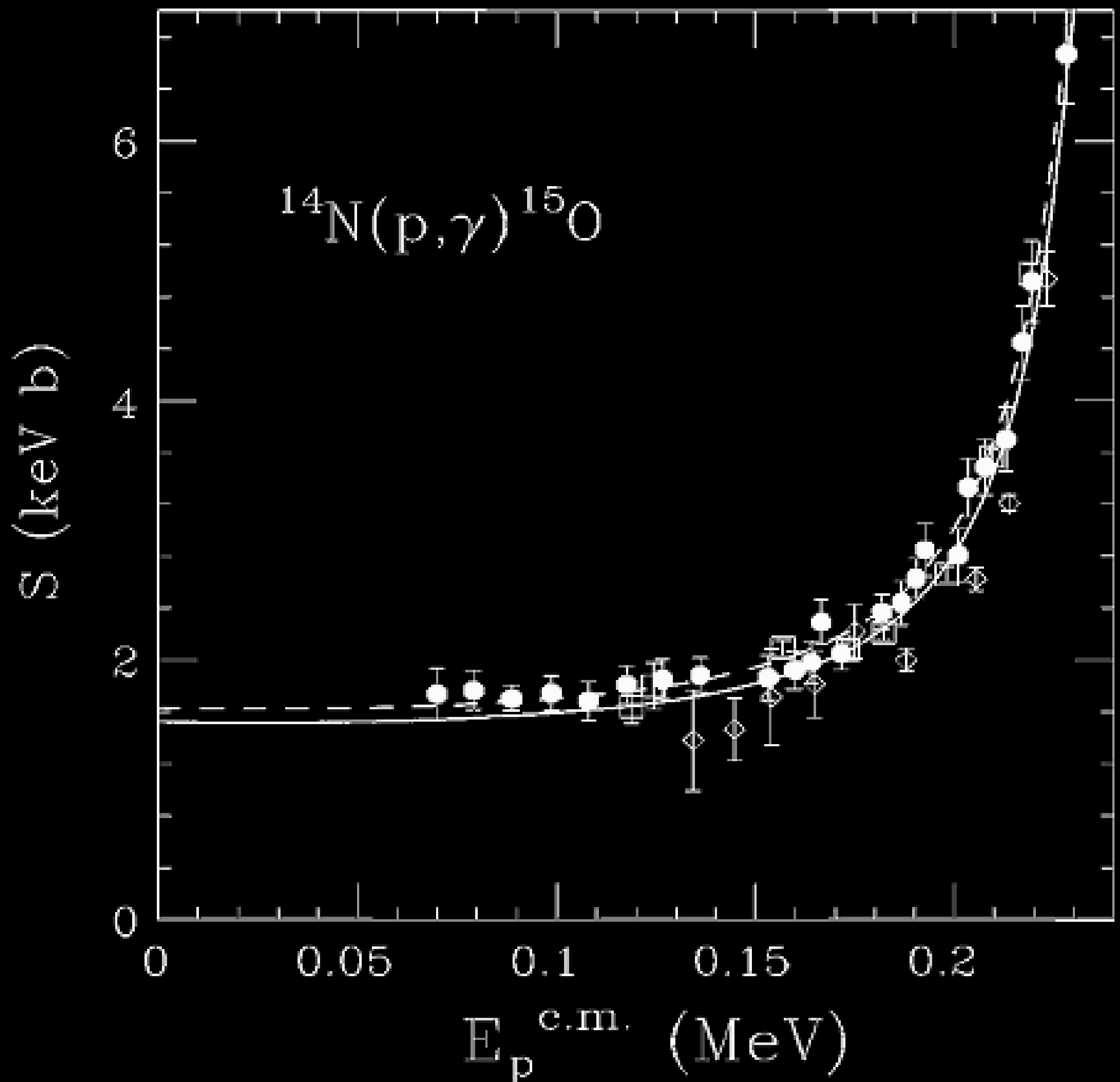
- Initial state $[{}^{14}\mathrm{N}(1_1^+) \otimes s_{1/2}]^{J_g=1/2}$
- g.s.

$$A[{}^{14}\mathrm{N}(1_1^+) \otimes p_{3/2}]^{J_g=1/2} +$$

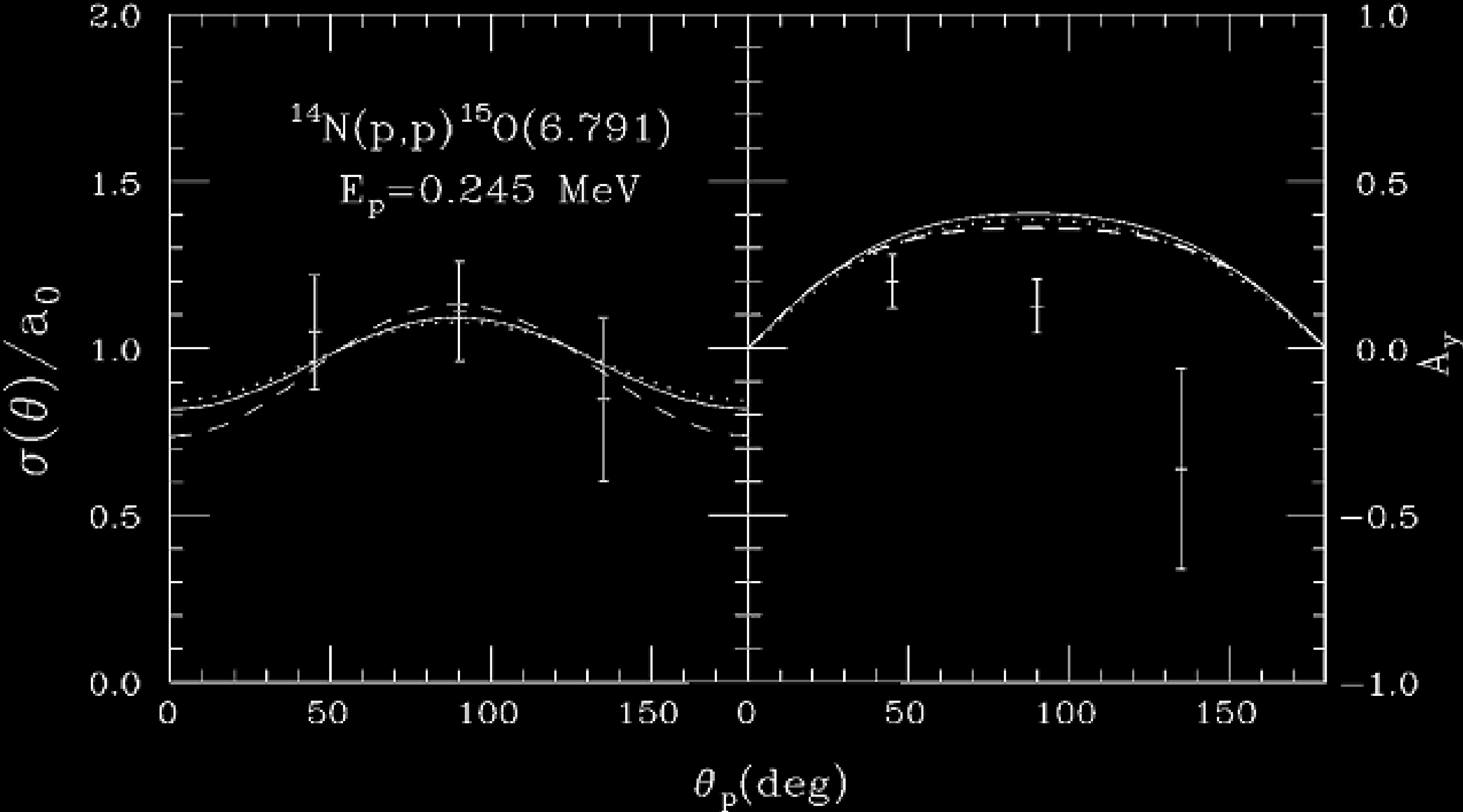
$$B[{}^{14}\mathrm{N}(1_1^+) \otimes p_{1/2}]^{J_g=1/2}$$

$\langle f \| \mathbf{r} \| i \rangle = \text{-}0.072R$ Cohen and Kurath $0.147R$

Total S factor



Angular distribution and analyzing power



Conclusions

- Transition to 3/2+ agrees well with existing data
- No significant contributions from subthreshold resonance
- Low energy S factor is nearly flat
- S(30) = 1.625 keVb