Experimental Challenge to the Cosmological Li Problem

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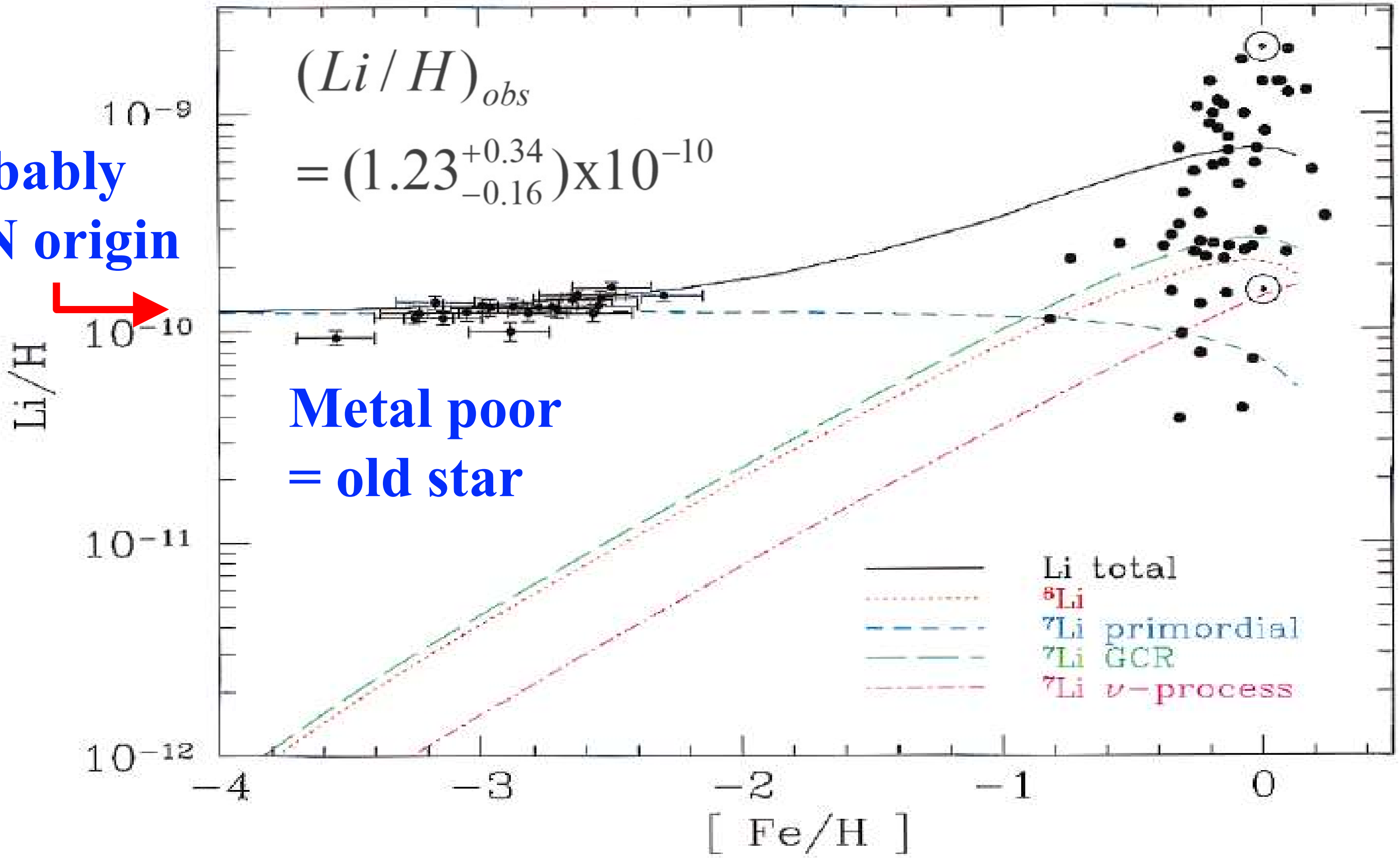
1. Cosmological Li Problem in BBN
2. ^{7}Be + n destruction channels
3. Other destruction channels of ^{7}Be
4. Summary

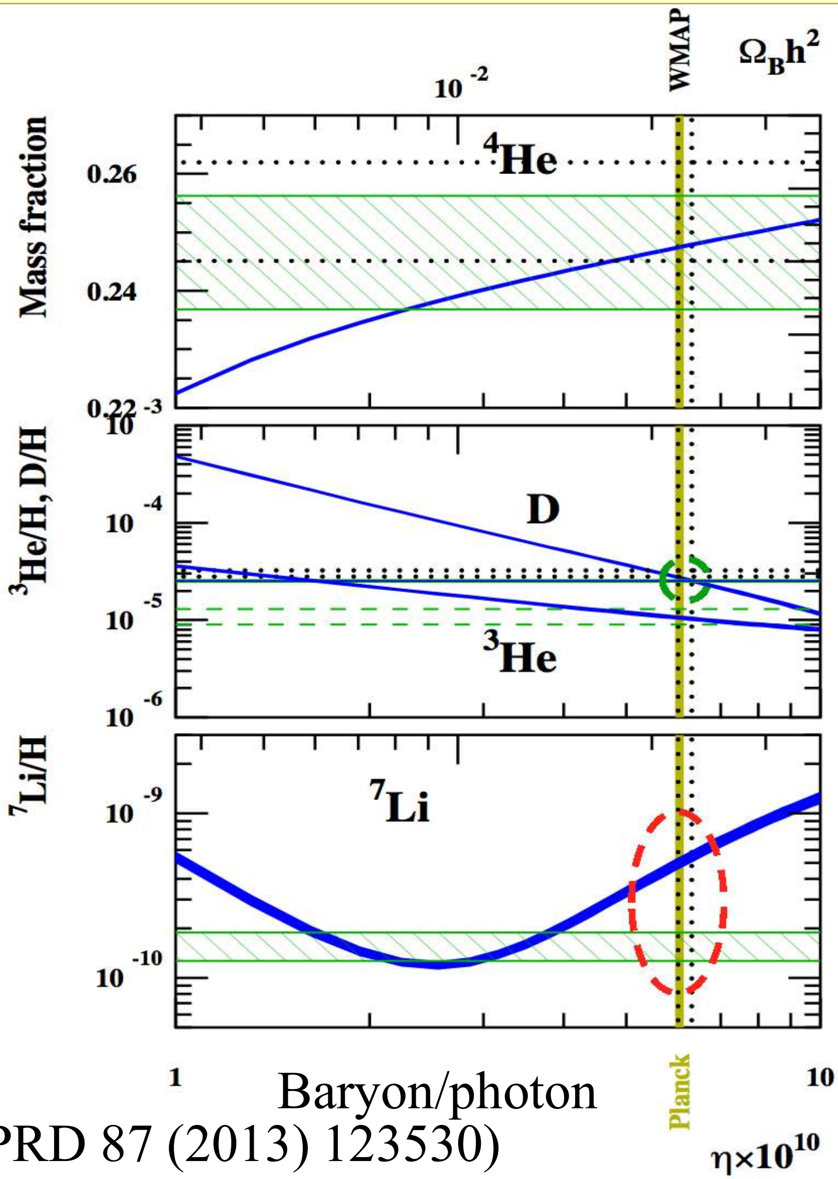
Observation of Primordial ^{7}Li Abundance

S. G. Ryan *et al*.,
Astrophys. J. 600 (2000) L57.

Probably BBN origin



Primordial Light Nuclides – Cosmological Li Problem



Baryon/photon

(Coc, PRD 87 (2013) 123530)

Microwave background Measurement:
Plank observation:
$\Omega_b h^2=(2.23\pm0.02)\mathrm{x}10^{-2}$

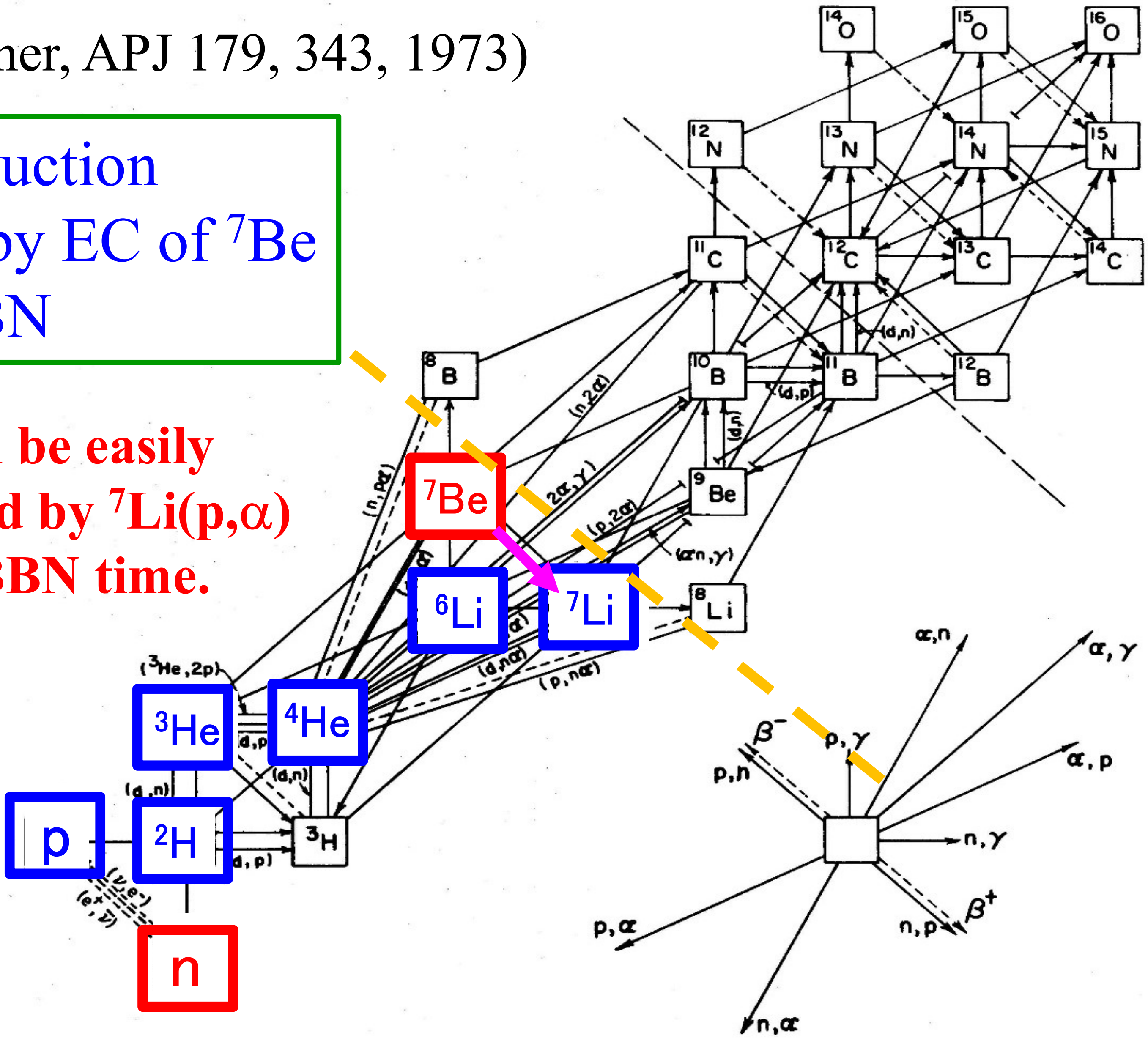
BBN calculation overestimate by a factor of ~3!

Primordial Nucleosynthesis (BBN)

(Wagoner, APJ 179, 343, 1973)

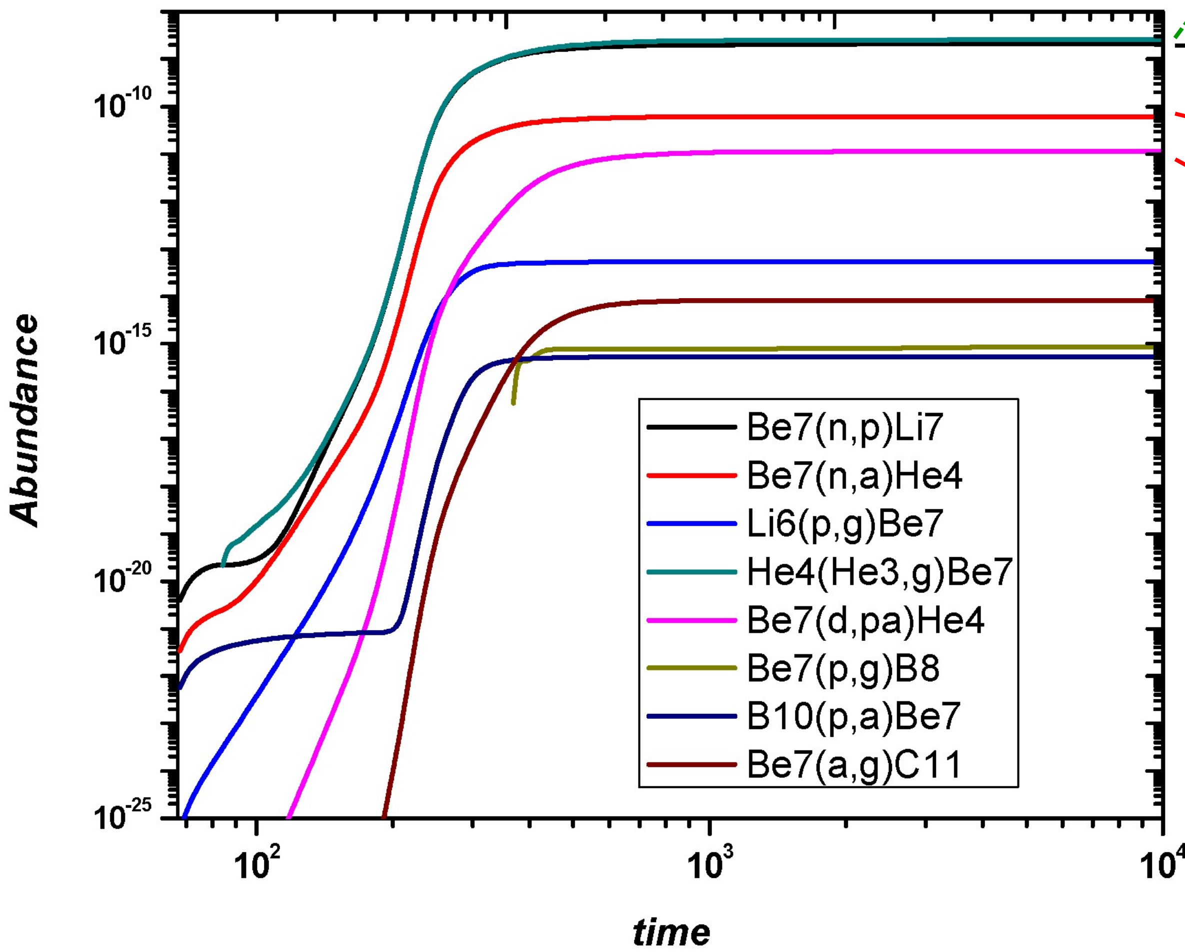
^{7}Li production mainly by EC of ^{7}Be after BBN

*** ^{7}Li can be easily destroyed by ^{7}Li(p,α) during BBN time.**



Primordial Light Nuclides -^{7}Li Problem-

Standard model BBN predictions (S. Hou, 2015)



Production of ^{7}Be

Destruction of ^{7}Be:

^{7}Be(n,p)^{7}Li

^{7}Be(n,α)^{4}He

^{7}Be(d,pα)^{4}He

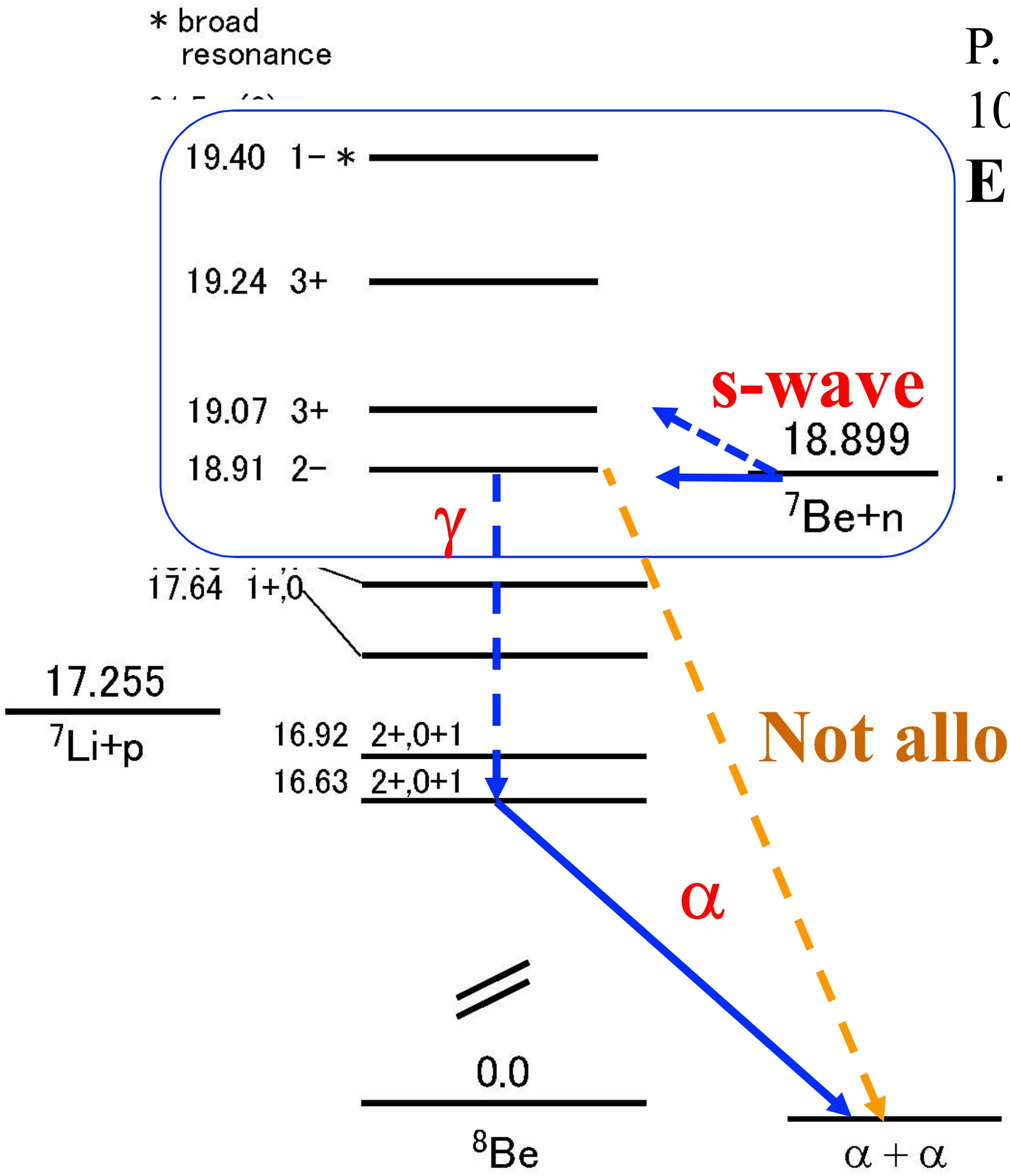
1. Fate of ^{7}Be by (n,α)

- Most unknown reaction for ^{7}Be destruction -

$^{7}Be(n,\alpha)^{4}He$ Reaction

P. Bassi, Il Nuovo Cimento XXVIII, 1049 (1963)

En = thermal energy



$^{7}Be(3/2^{-}) \otimes n(1/2^{+})$

$l = 0$

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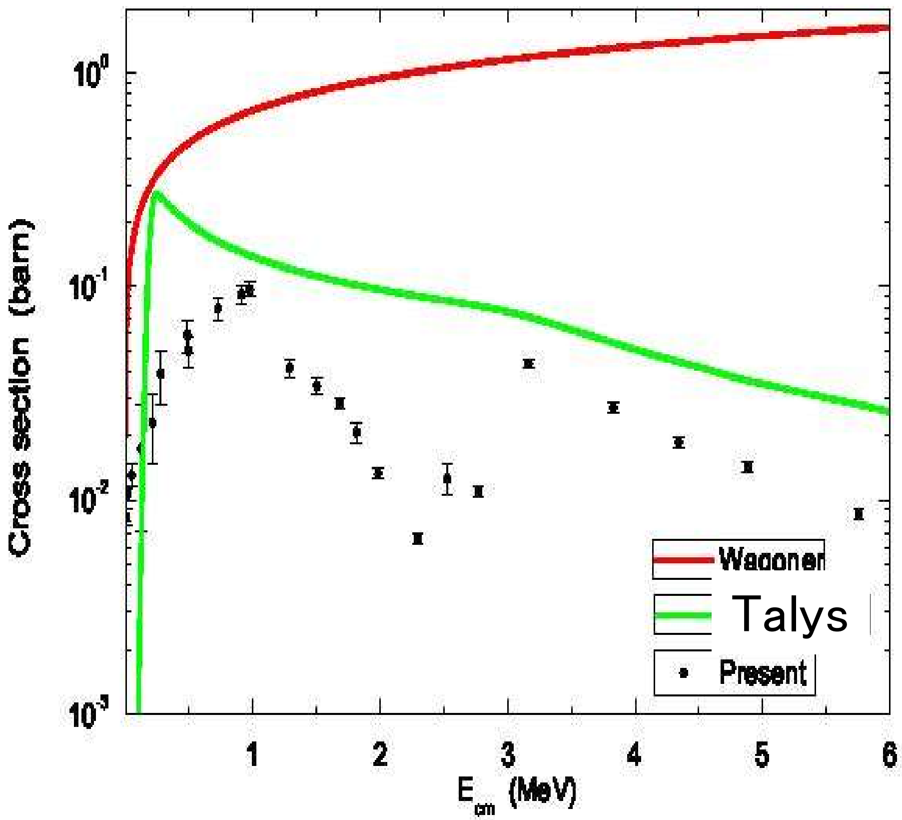
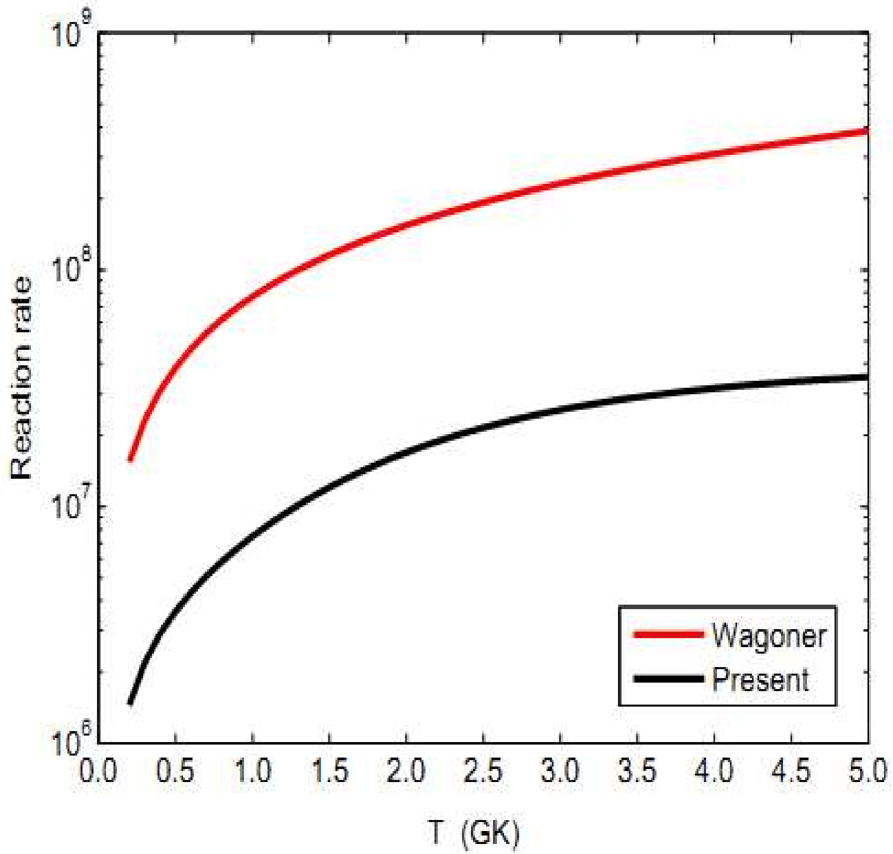
New estimate of ^{7}Be(n,α)^{4}He cross sections

Hou, He, Kubono, and Chen, PRC **91** (2015) 055802

Re-evaluation from ^{7}Li(p,α)^{4}He reaction ⟸

$$\sigma_n = \sigma_{n_0} + \sigma_{n_1} = \frac{P_\ell^{n_0}}{P_\ell^{p_0}}\sigma_{p_0} + \frac{P_\ell^{n_1}}{P_\ell^{p_1}}\sigma_{p_1},$$



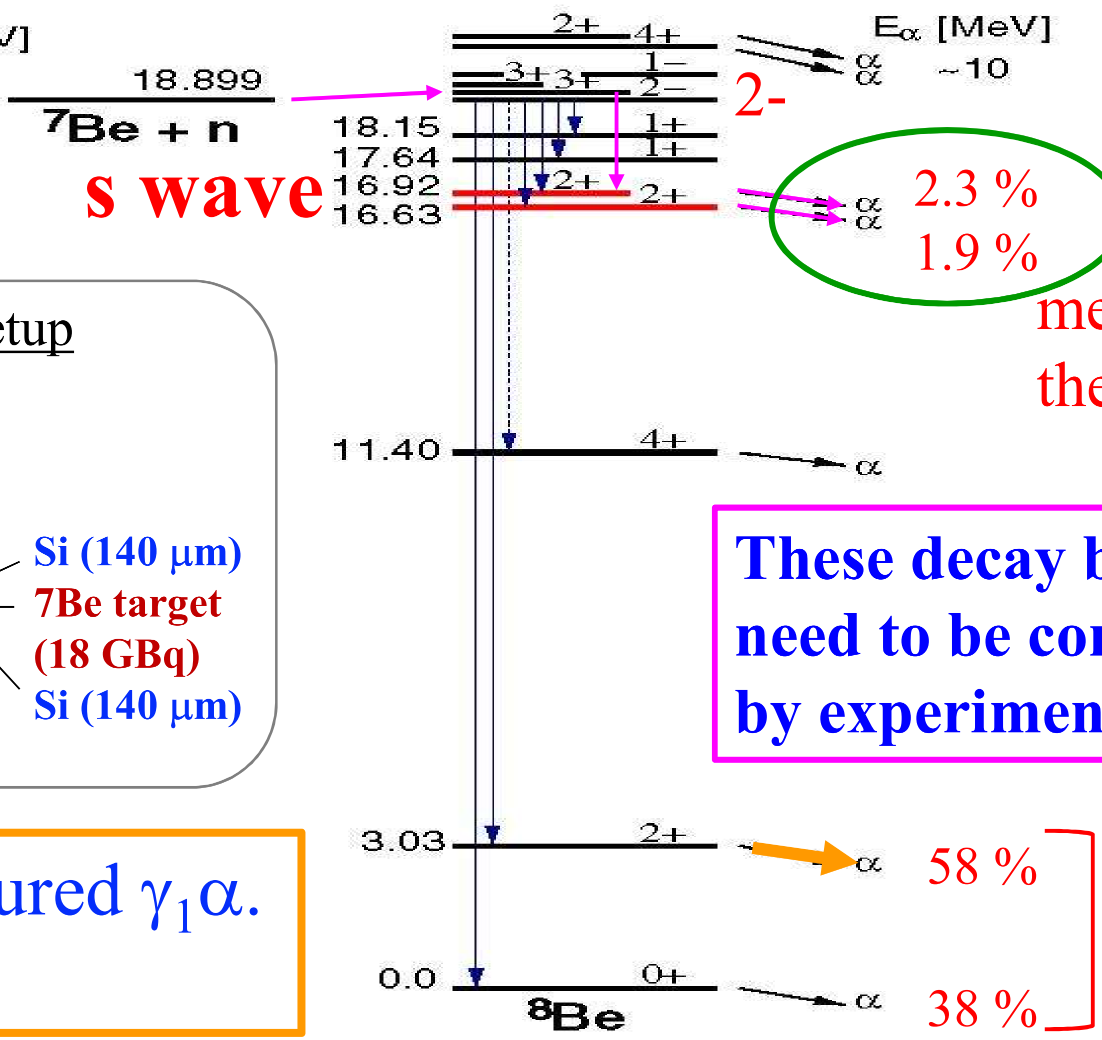


Several experiments made and being made

1. RCNP – time-rev. method
   (Kyoto-RIKEN-RCNP-Tohoku)
2. ISRAEL - direct measurement
3. n-TOF - direct measurement
4. Legnaro - Trojan Horse Method
5. CRIB/RIBF - Trojan Horse Method
6. JAEA – Branching ratio
7. FSU – 7Be(d,a)
8. . . .

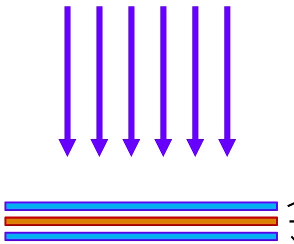
^{7}Be(n,α) experiment at n-TOF

(Barbagallo, PRL 117, 152701, 2016)



Theoretical estimate

n-TOF exp. setup



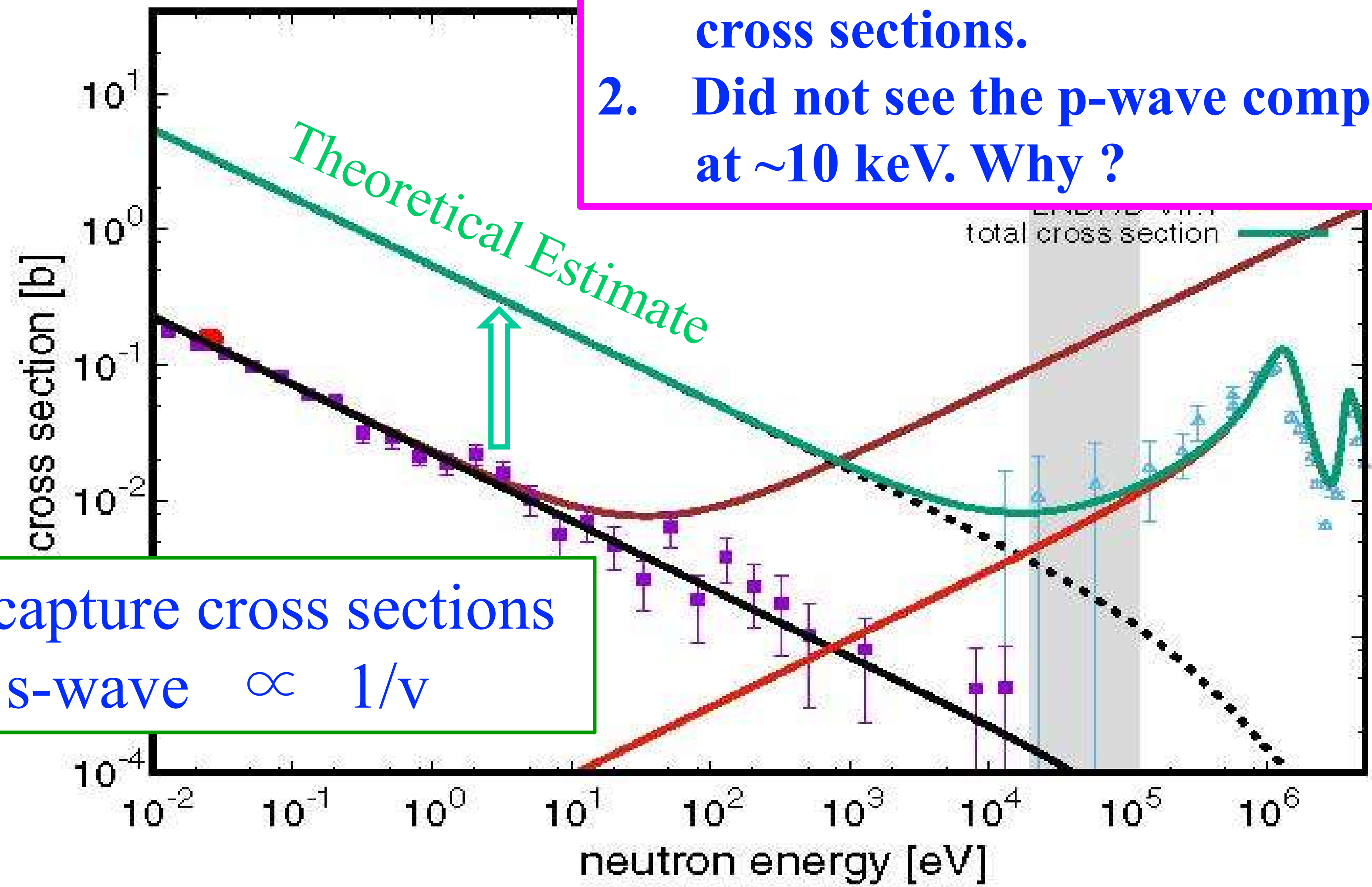
These decay branches need to be confirmed by experiment

M Gai measured $\gamma_1\alpha$. at ~50 keV.

n-TOF Result; Cross sections of $^{7}Be(n,\alpha)$

Problems:

1. **Used theoretical estimate for total cross sections.**
2. **Did not see the p-wave component at ~10 keV. Why ?**

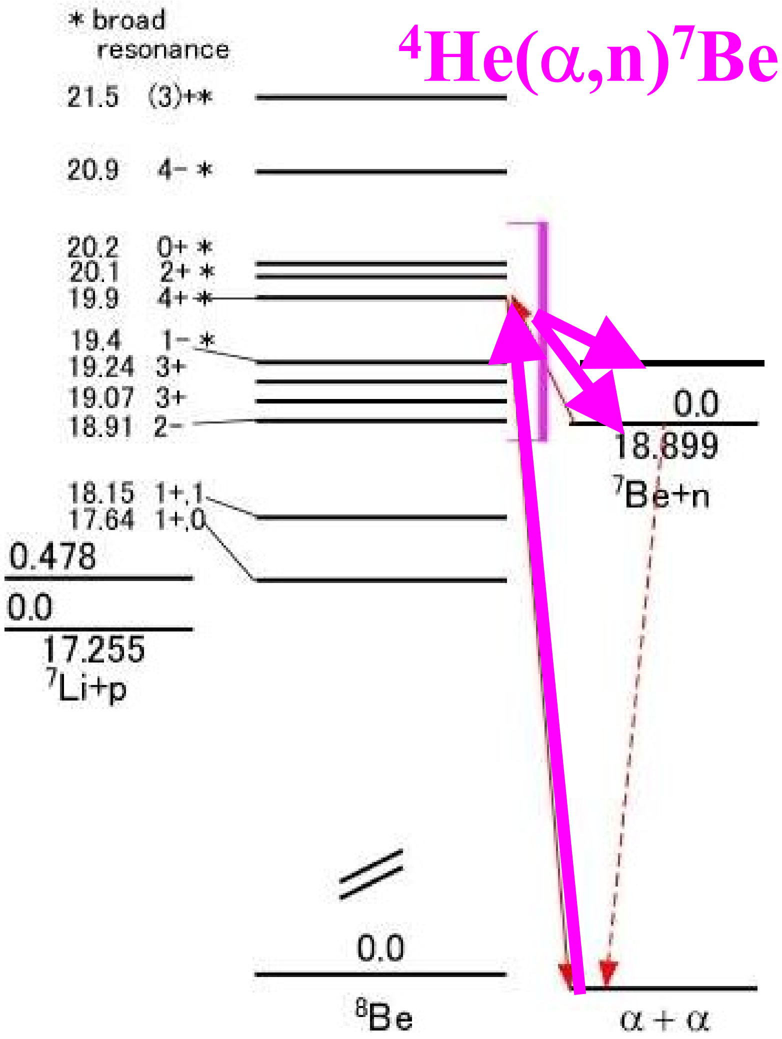


n-capture cross sections of s-wave $\propto$ 1/v

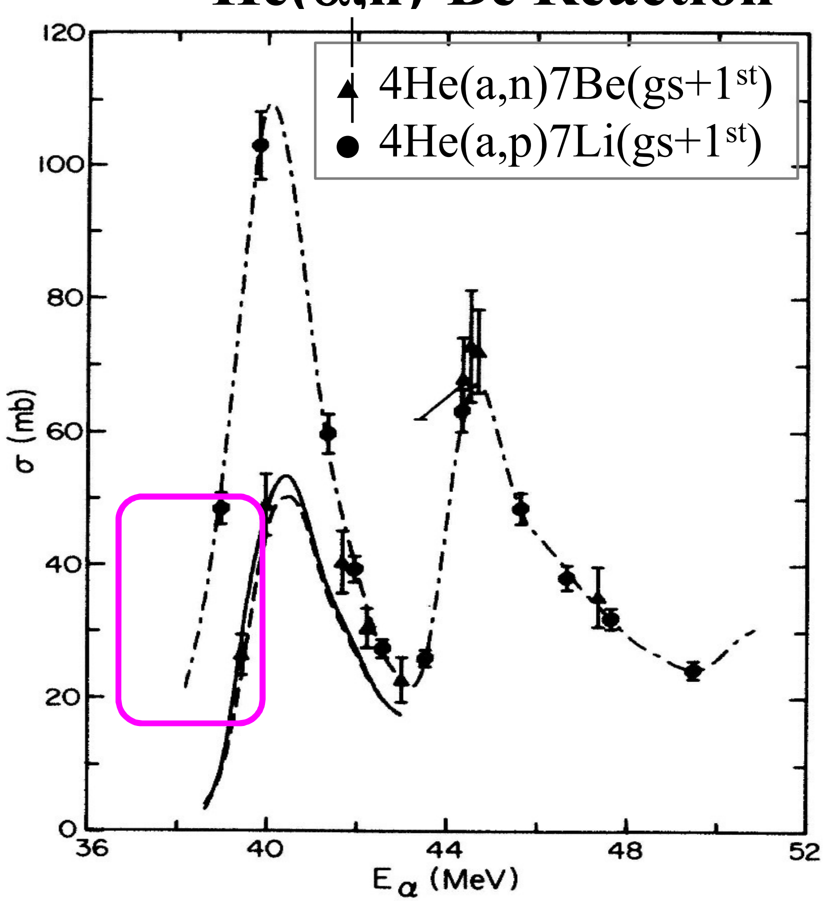
^{7}Be(n,α)^{4}He Study by ^{4}He(α,n)^{7}Be

Use the time-reverse reaction, ^{4}He(α,n)^{7}Be

Kawabata, Kubono, PRL 118(2017) 052701



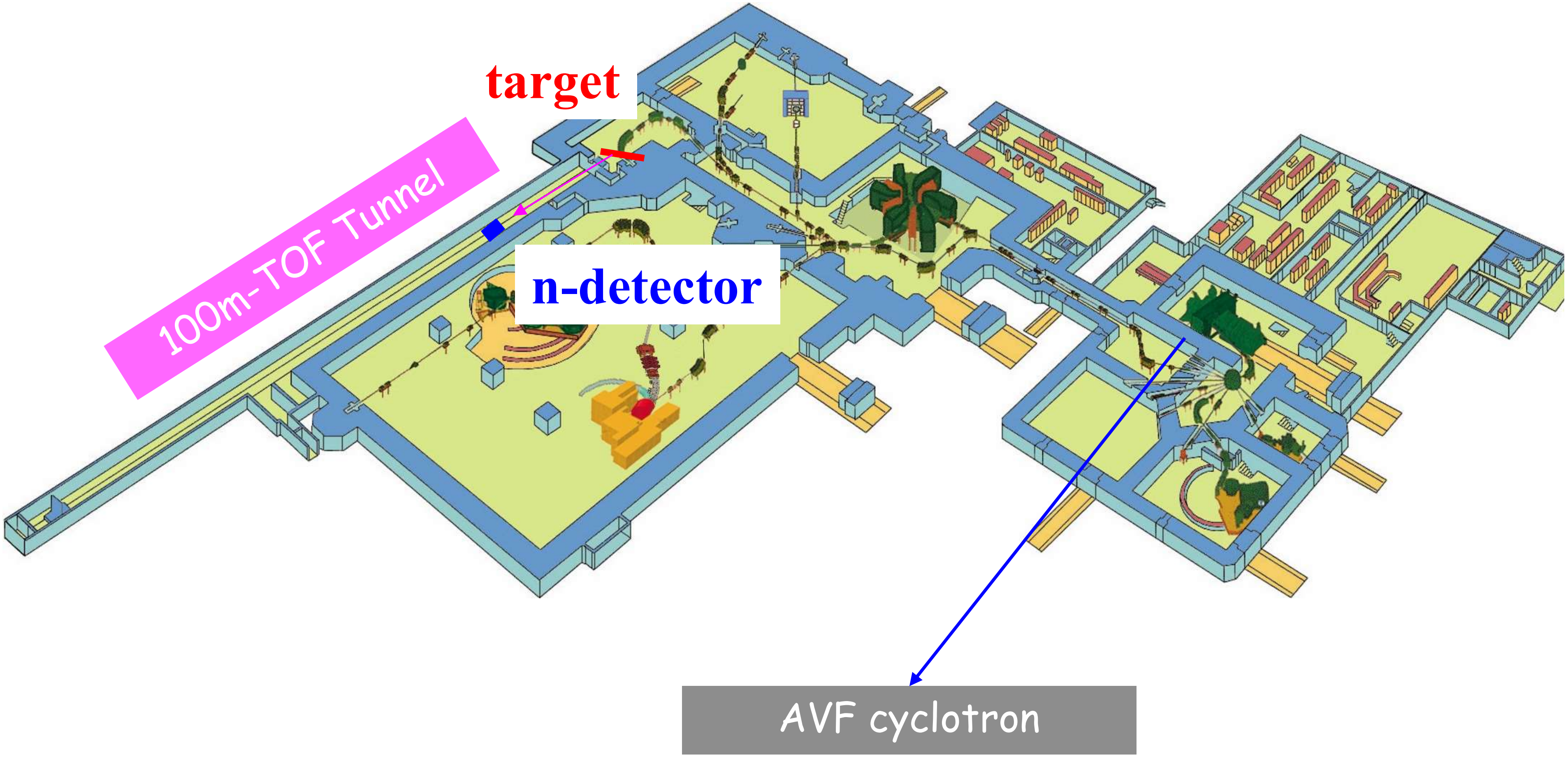
^{4}He(α,n)^{7}Be Reaction



(King, PRC 16.1712 (1977))

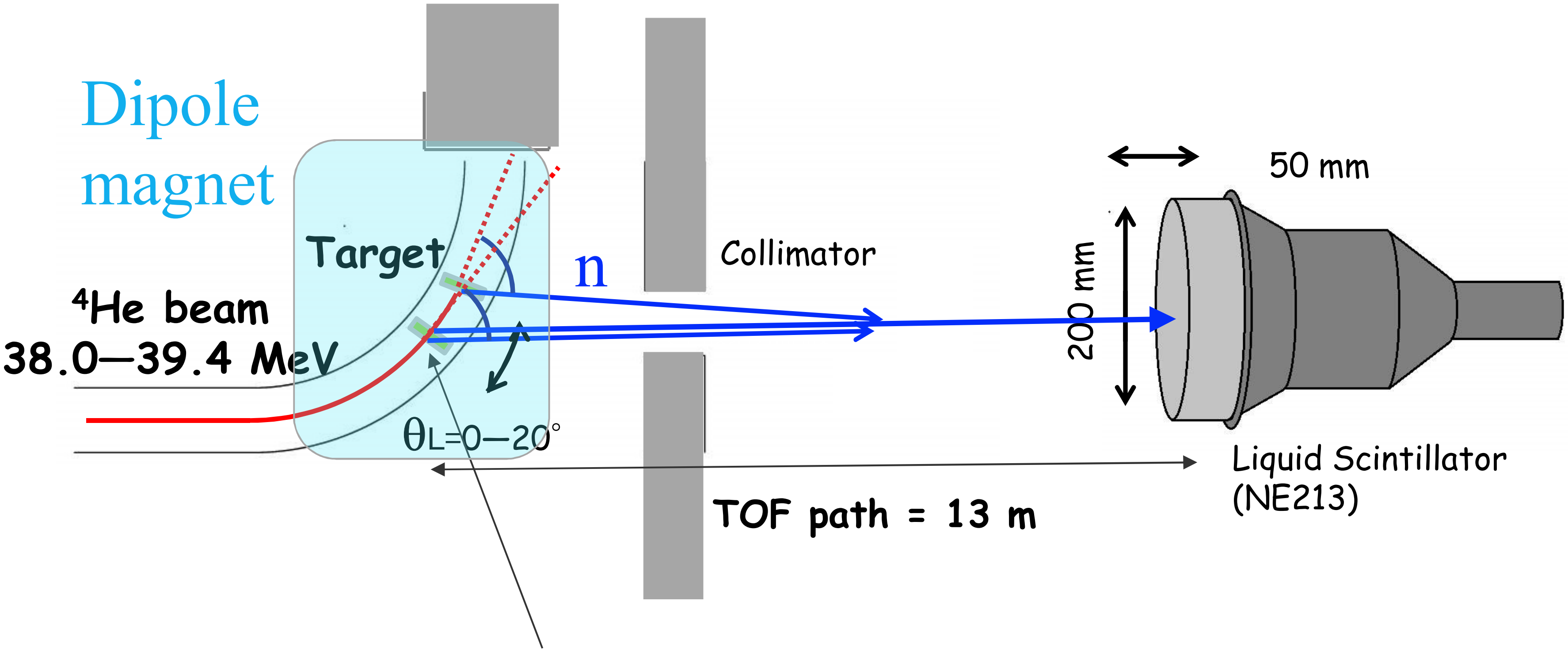
Experimental Facility

Neutron TOF Facility in RCNP, Osaka.

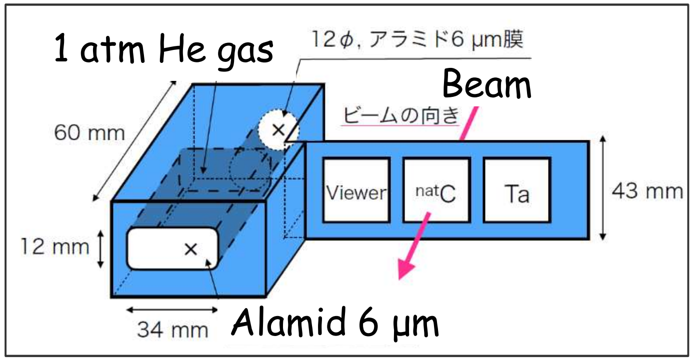


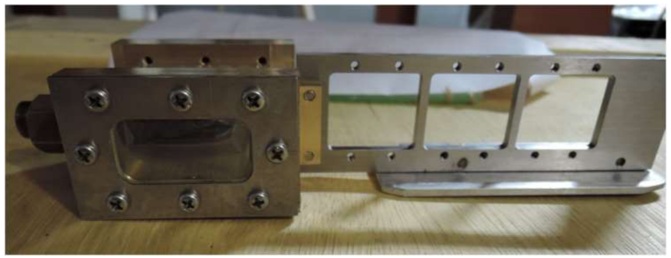
Experimental Setup II

Neutron TOF Facility in RCNP, Osaka.



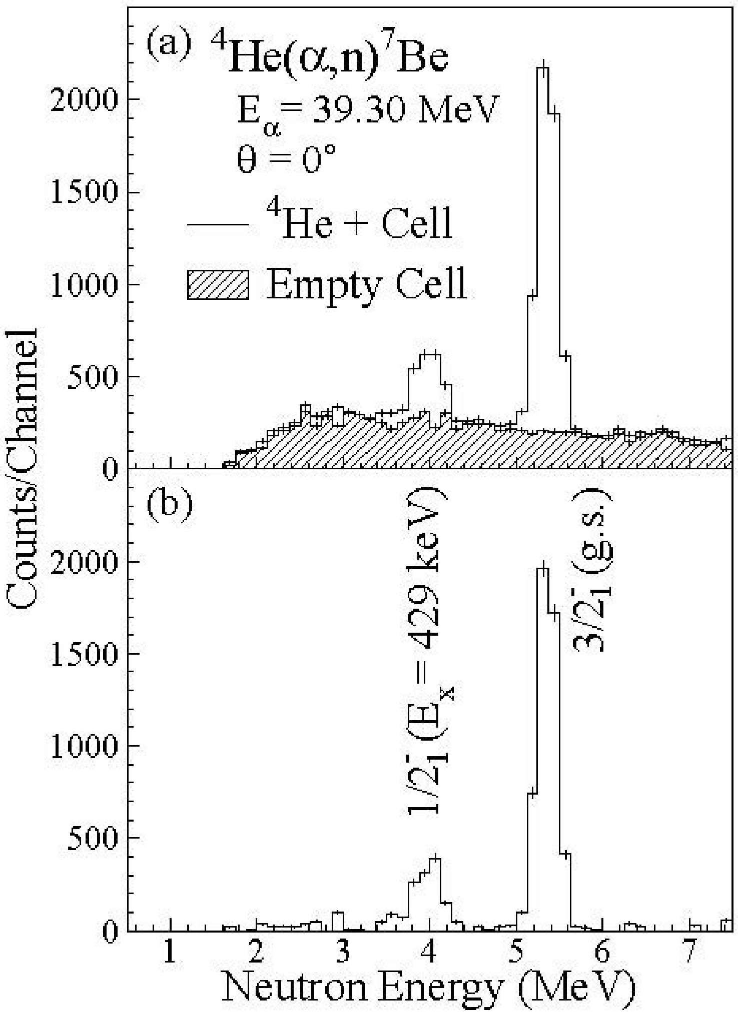
Target

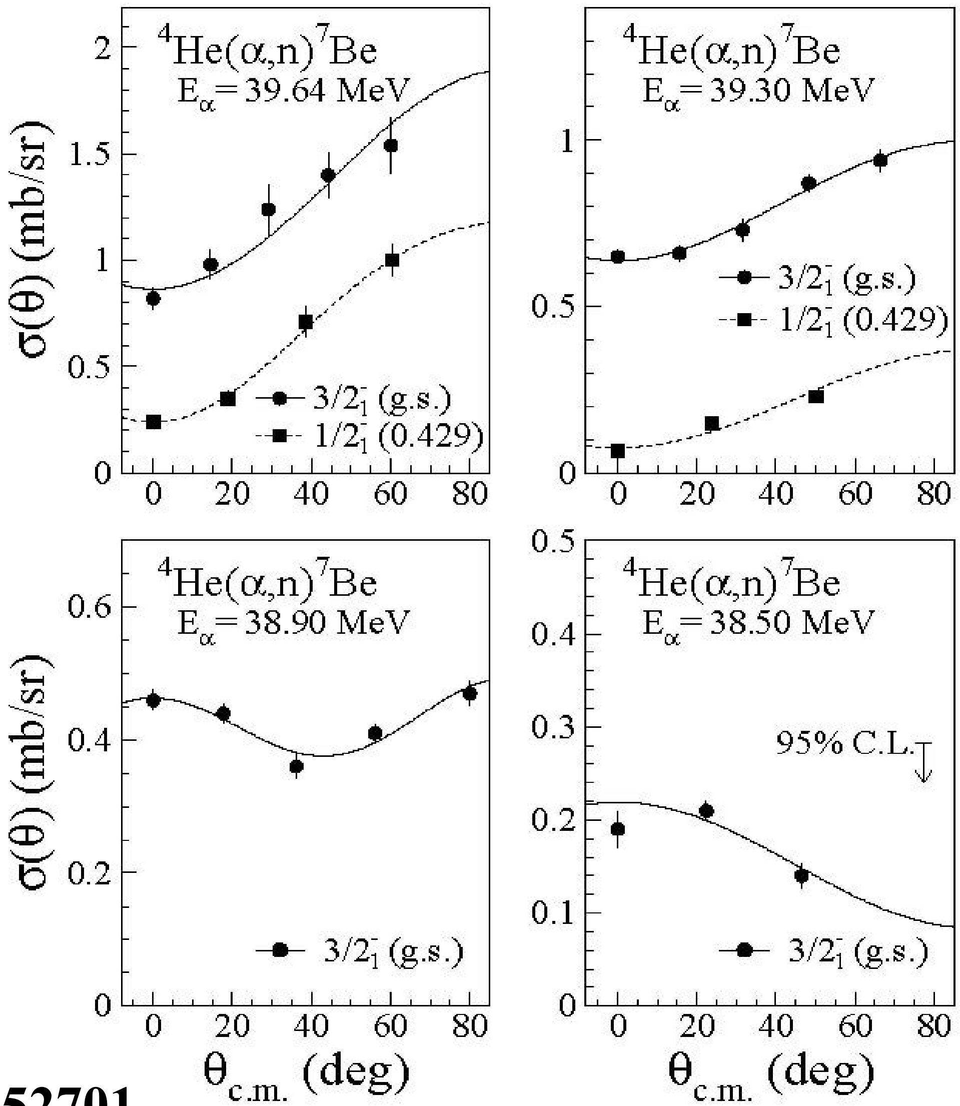




Experimental Results

$$\frac{d\sigma}{d\Omega} = \frac{\sigma}{4\pi}\sum_{L=0}^{L_{max}} A_L P(\cos\theta)$$



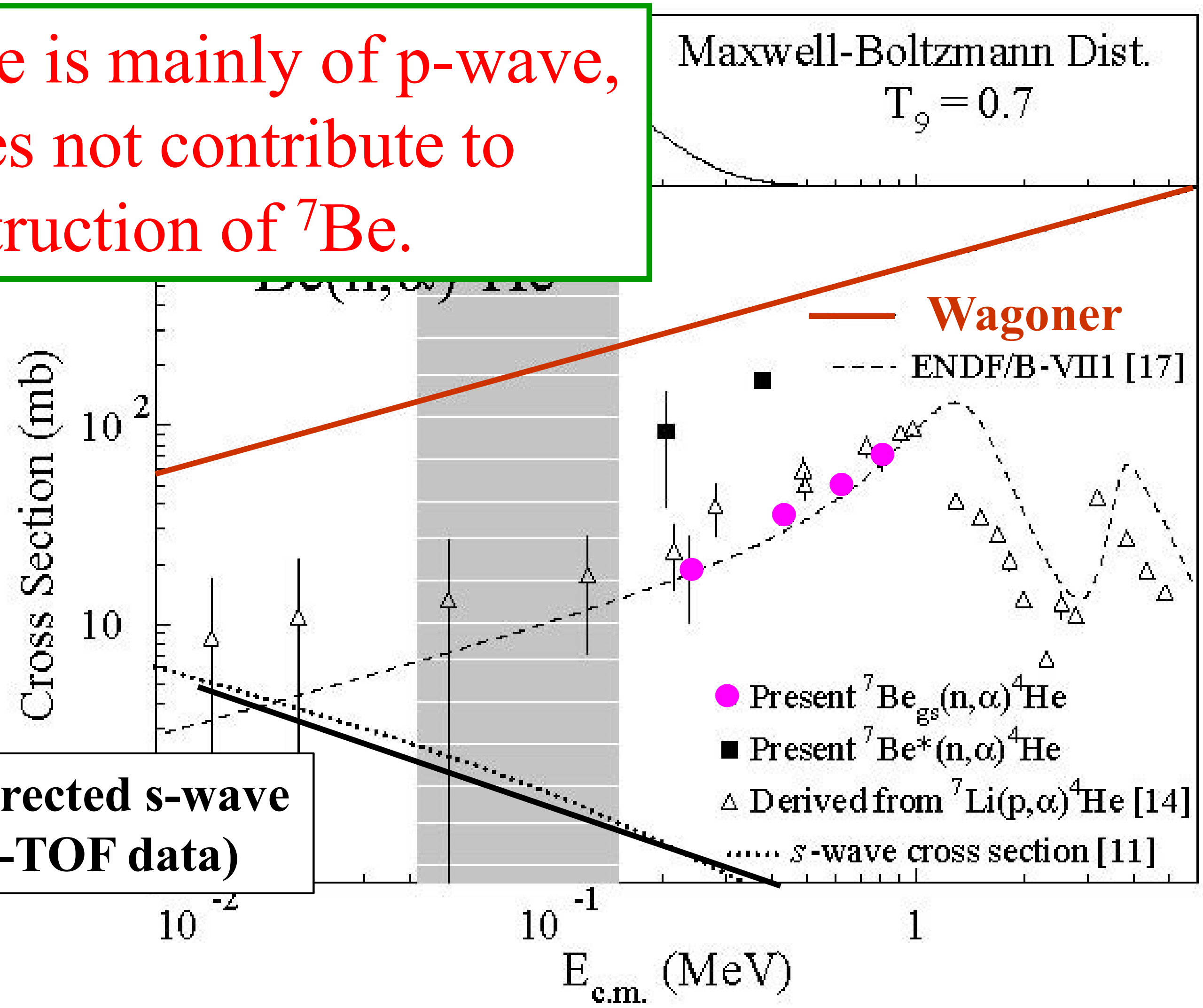


Kawabata, Kubono, PRL 118(2017) 052701

Experimental Results of ^{7}Be(n,α)

Kawabata, Kubono, PRL 118(2017) 052701

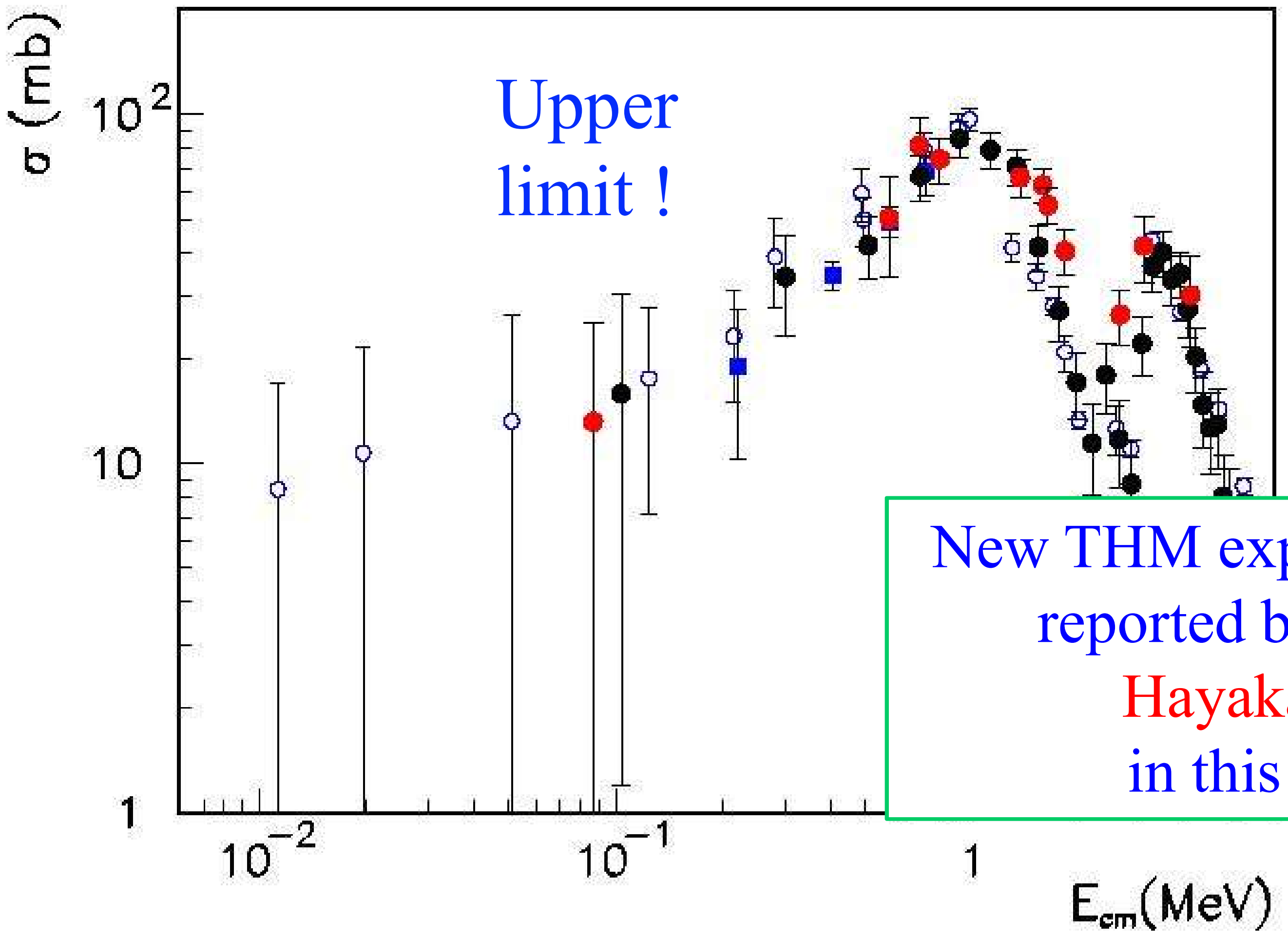
^{7}Be(n,α)^{4}He is mainly of p-wave, and does not contribute to destruction of ^{7}Be.



Theoretical corrected s-wave contribution (n-TOF data)

Trojan Horse Method for $^7Be(n,\alpha)$

- L. Lamia, APJ 850, 175
- Kawabata, PRL
- Hou, PRC



New THM experiments will be reported by Lamia and Hayakawa soon in this session !

Conclusion for $^{7}Be(n,\alpha)^{4}He$ reaction in BBN

1. **The p-wave cross sections dominate at the BBN temperatures.**

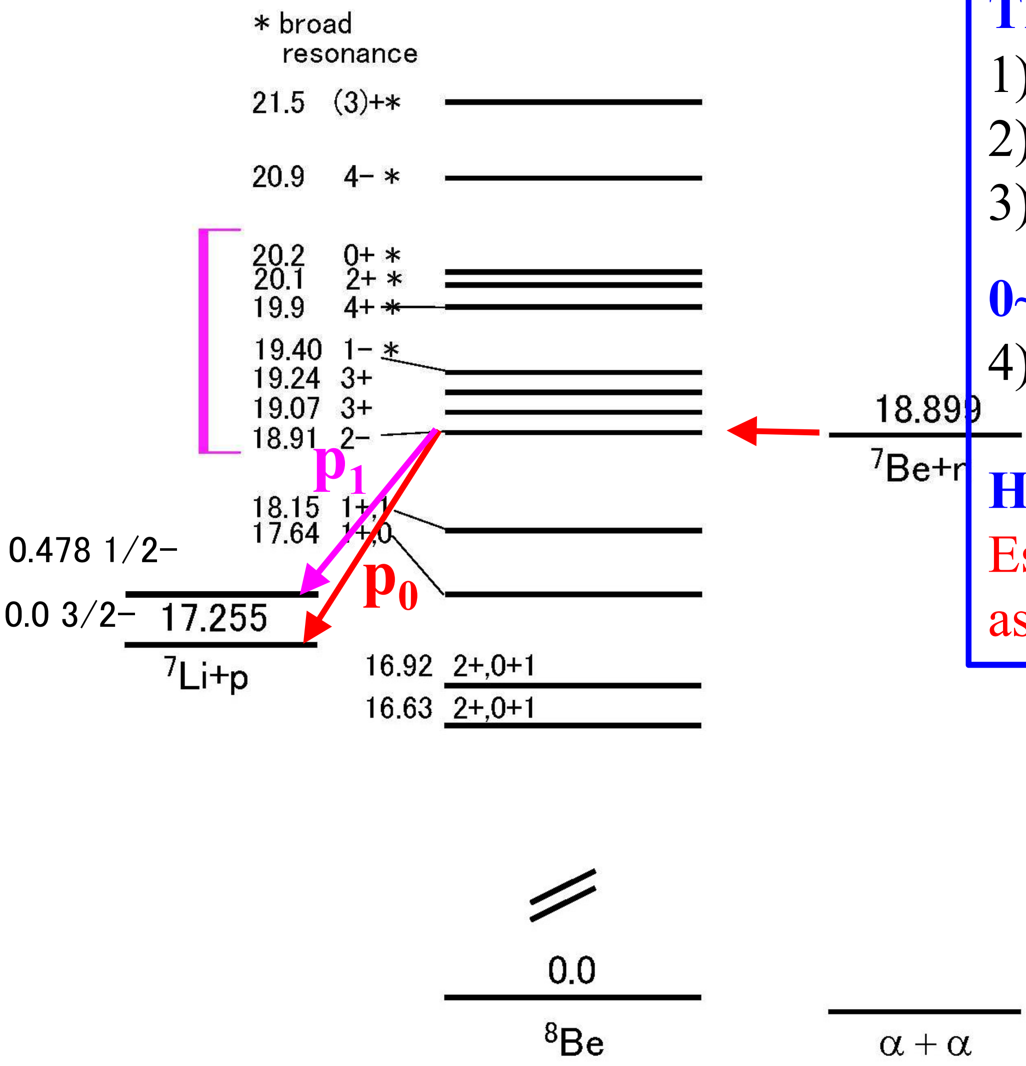
2. **The total cross sections (s +p) is about one order of magnitude smaller than the Wagoner rate.**

3. **The $^{7}Be(n,\alpha)^{4}He$ reaction does not solve the Li problem in BBN.**

2. Fate of ^{7}Be by (n,p)

- **The major destruction reaction. Any uncertainty, well known ? -**

^{7}Be(n,p), the major destruction reaction



Thermal energy:

1) Hanna, Phylos. Mag., 46 (1955) 381
2) Newson, PR 108 (1957) 1294
3) Macklin, PR 109 (1958) 105

0~13 keV:

4) Koehler, PRC 37 (1988) 917

Higher energies, 10keV – 3MeV;

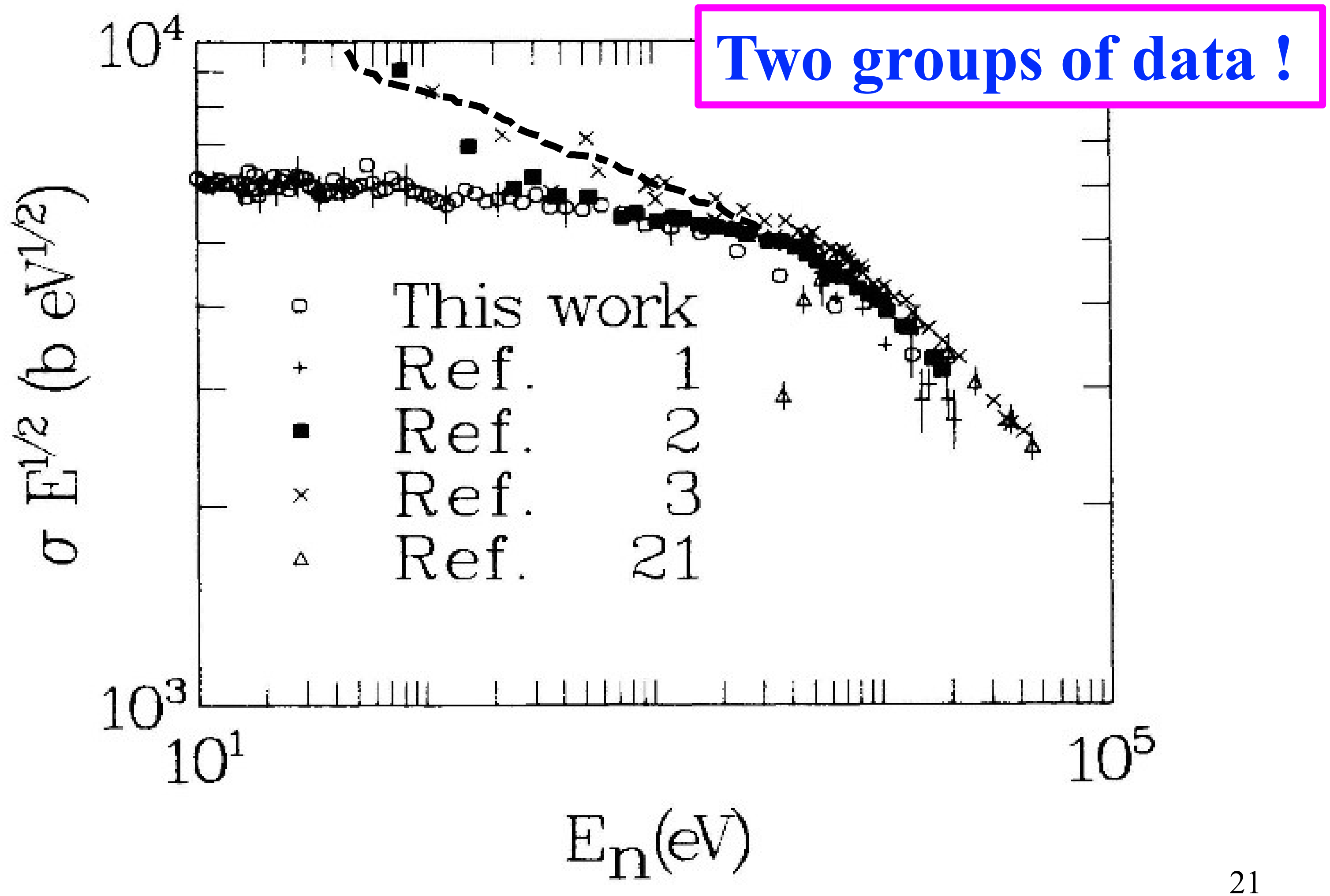
Estimated by the ^{7}Li(p,n)^{7}Be data, assuming only ^{7}Be(n,p_0)^{7}Li(g.s.)

Problem:

The p_1 transition was neglected. This could be important except for 2^-. Need to be studied experimentally.

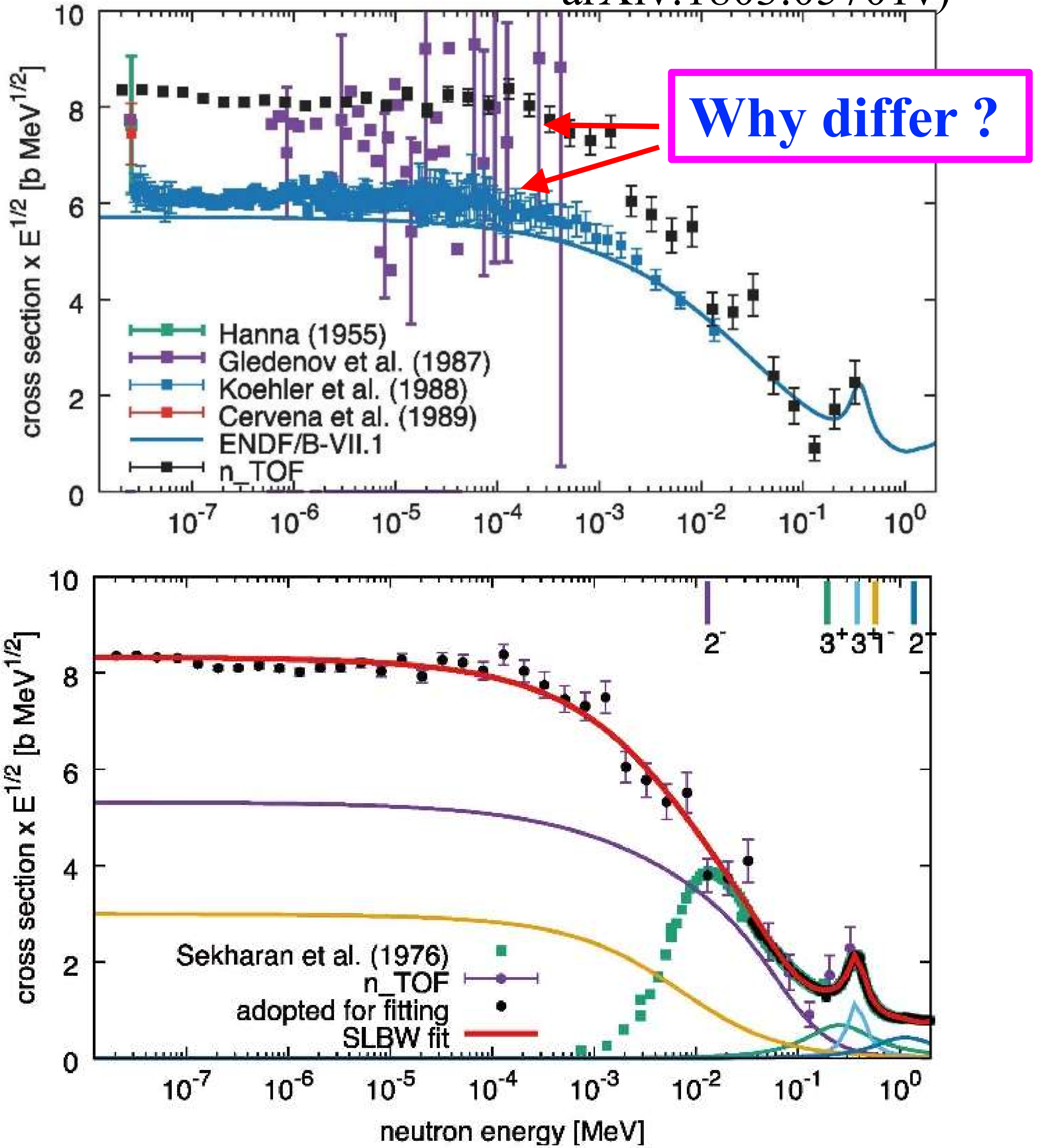
$^{7}Be(n,p)Li$ reaction cross sections

Koehler, PRC 37 (1988) 917



$^{7}Be(n,p)^{7}Li$ Measured @n-TOF

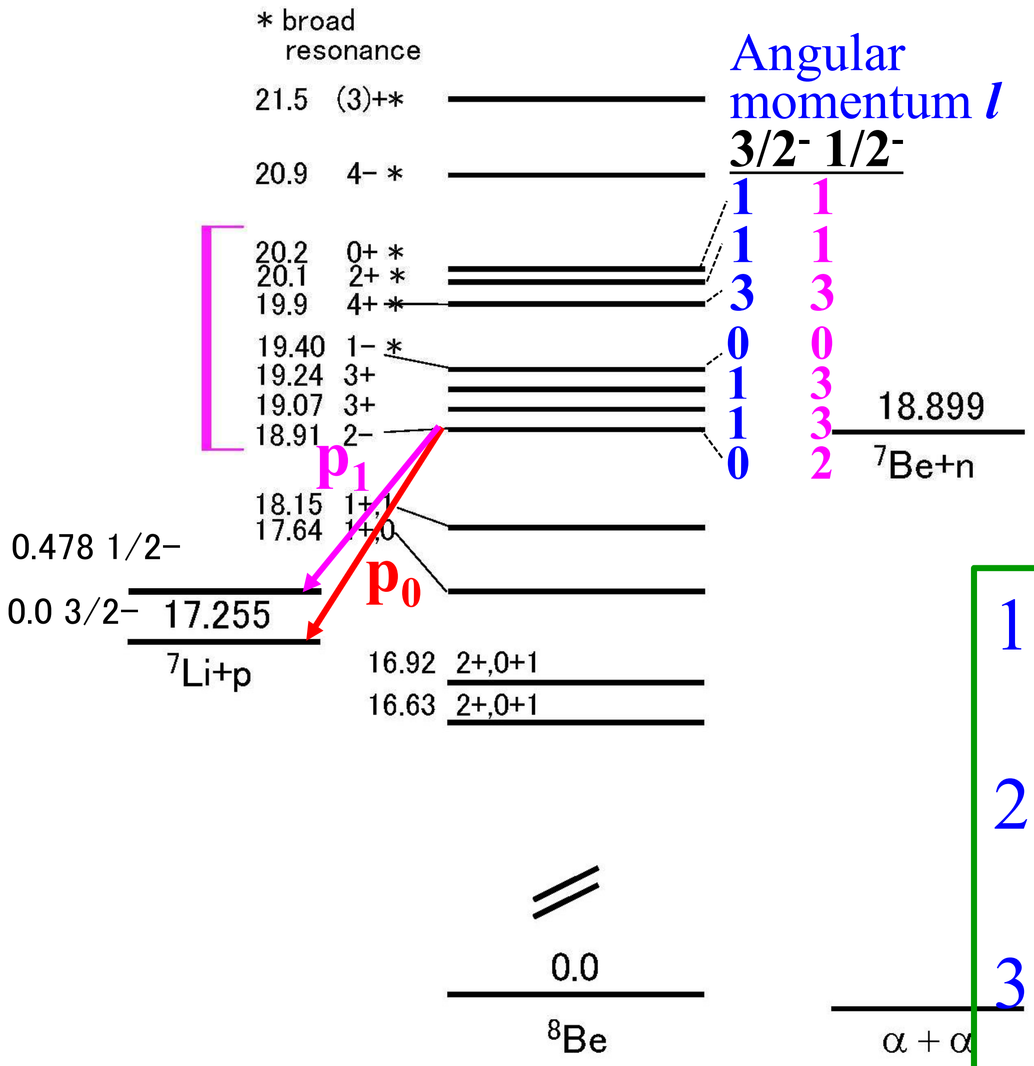
(Damone, et al. arXiv:1803.05701v)



Problem:
The total cross sections were obtained assuming s-wave transitions for all.
But, they are mostly non s-wave.

-> Need to measure angular distributions

^{7}Be(n,p) reaction and the spin selection rule



2^{-}: ^{7}Li$(3/2^{-})\otimes$n$(1/2^{+})$

$l = 0, 2$

^{7}Li$(1/2^{-})\otimes$n$(1/2^{+})$

$l = 2$

1. 2-, 3+ decay with different l.
2. 1-, 0+,2+, 4+ with same l.
3. Only 2- and 1- have s-wave decay.

Measurement of the branching ratio for the $^7Be(n,p)^7Li$ reaction

(Iwasa,SK, ..)

The branching ratios p_1/p_0 were measured for these resonances at JAEA tandem facility, using ENMA spectrometer.

Preliminary

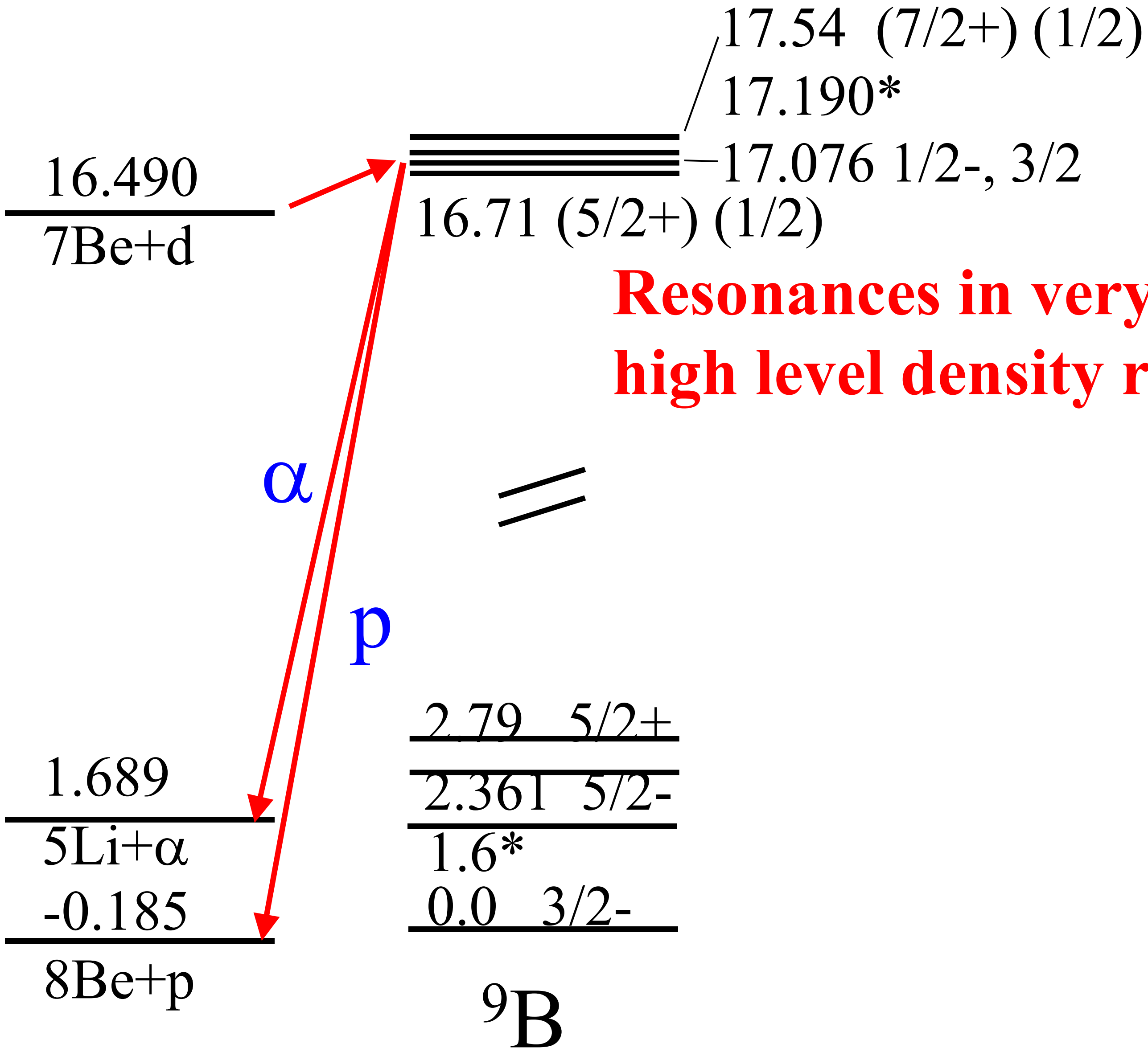
Significant decay branches for p_1 were observed for the resonances except for the lowest 2- resonance.

Similar result was obtained by THM.
Waite for Hayakawa talk.

3. Fate of ^{7}Be by other channels

- d, 3He, t induced reactions? -

$^{7}Be(d,p)$ and (d,α) reactions



Resonances in very high level density region !

$^{7}Be(d,\alpha)^{5}Li$ Reaction

Ingo Wiedenhoever reported (first day of this symposium):

- The excitation function of $^{7}Be(d,p)$ and $^{7}Be(d,alpha)$ with good sensitivity into the Gamow window of BBN.

- Some new resonances in the (d,alpha) cross sections were discovered, and this reaction is dominating over the (d,p) reaction. This result reduce the Li problem by ~17%.

4. Other possibilities for the Li Problem

- **Other reactions in BBN ; $^{3}He(\alpha,\gamma)$, $^{2}H(p,\gamma)$,. .**

Summary on Li Problem in BBN

1. ^{7}Be(n,α) reaction is now reasonably well studied, and would not contribute much to the ^{7}Be destruction.
2. ^{7}Be(n,p) reaction needs to be refined better by experiments considering the spin selection.
3. ^{7}Be+d channels may influence to the ^{7}Be destruction.
4. ^{7}Be+^{3}He, t, α channels still are not well investigated yet. They should be studied carefully.

1. **Further experiments are required for reaction rates.**
2. Other possibilities of **new unknown physics** for BBN.
3. **Further work in observation** is also highly welcome.