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Experimental study of the ^{7}Be(n,p_1)^{7}Li* reaction for the cosmological lithium problem

N. Iwasa,[a] S. Ishikawa,[a] S. Kubono,[b] K. Asada,[a] D. Guru,[a] S. Hayakawa,[c] K. Hirose,[d] T. Kawabata,[e] K. Kominato,[a] H. Makii,[d] M. Matsuda,[d] S. Nishimura,[b] K. Nishio,[d] R. Orlandi,[d] T. Sakakibara[a]

[a] *Tohoku Univ.*, [b] *RIKEN RNC*, [c] *CNS, Univ. Tokyo*, [d] *ASRC, JAEA*, [e] *RCNP, Osaka Univ.*

Motivation

◊ Big Bang model: expansion of the universe, cosmic microwave background, Big Bang nucleosynthesis (BBN)

(The primordial abundance of d, ^{3}He and ^{4}He are well reproduced.)

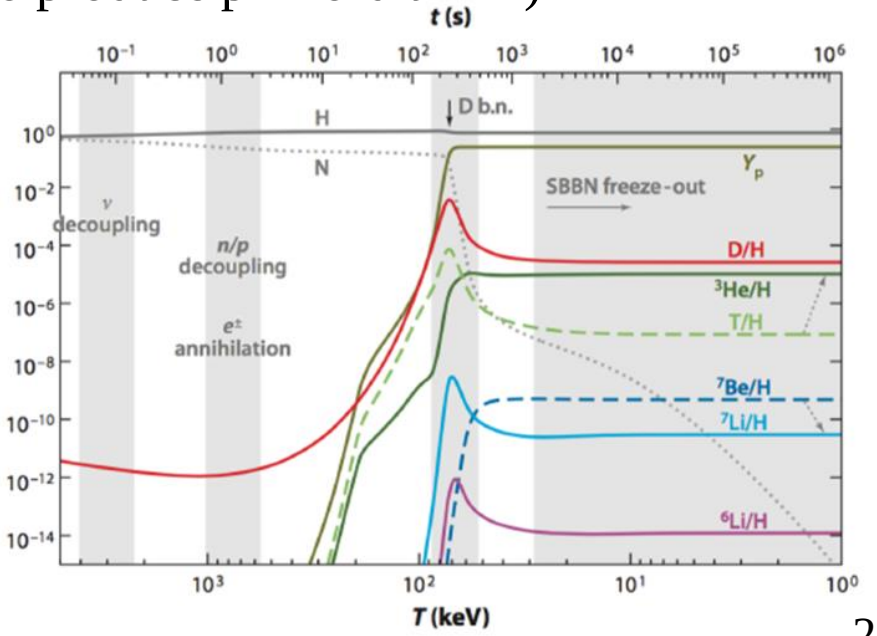
◊ The primordial abundance of ^{7}Li is overestimated by a factor of three to four.
→ cosmological Li problem

(1) $t(\alpha,\gamma)^7\mathrm{Li}, ^7\mathrm{Be}(n,p)^7\mathrm{Li} \longrightarrow$ destructed by $^7\mathrm{Li}(p,\alpha)^4\mathrm{He}$

(2) $^3\mathrm{He}(\alpha,\gamma)^7\mathrm{Be} \xrightarrow{\mathrm{EC}} {}^7\mathrm{Li}$ (dominate process to produce primordial ^{7}Li)

If reaction rate of ^{7}Be destruction was larger than that used in BBN model, the Li problem might be solved.

	BBN predictions	observations
$^2\mathrm{H}/^1\mathrm{H}$	$(2.45\pm0.05)\times10^{-5}$	$(2.53\pm0.04)\times10^{-5}$
$^3\mathrm{He}/^1\mathrm{H}$	$(1.07\pm0.03)\times10^{-5}$	$(0.9\sim1.3)\times10^{-5}$
$^4\mathrm{He}/^1\mathrm{H}$	0.2484 ± 0.0002	0.2449 ± 0.0040
$^7\mathrm{Li}/^1\mathrm{H}$	$(5.61\pm0.26)\times10^{-10}$	$(1.58\pm0.31)\times10^{-10}$



M. Pospelov, Annu. Rev. Nucl. Part. Sci. **60**, 539-568 (2010)

Motivation

◊ ^{7}Be(n,p)^{7}Li : the most important destruction reaction

reaction rate used in BBN model were deduced from

Direct measurements were reported up to 13.5keV

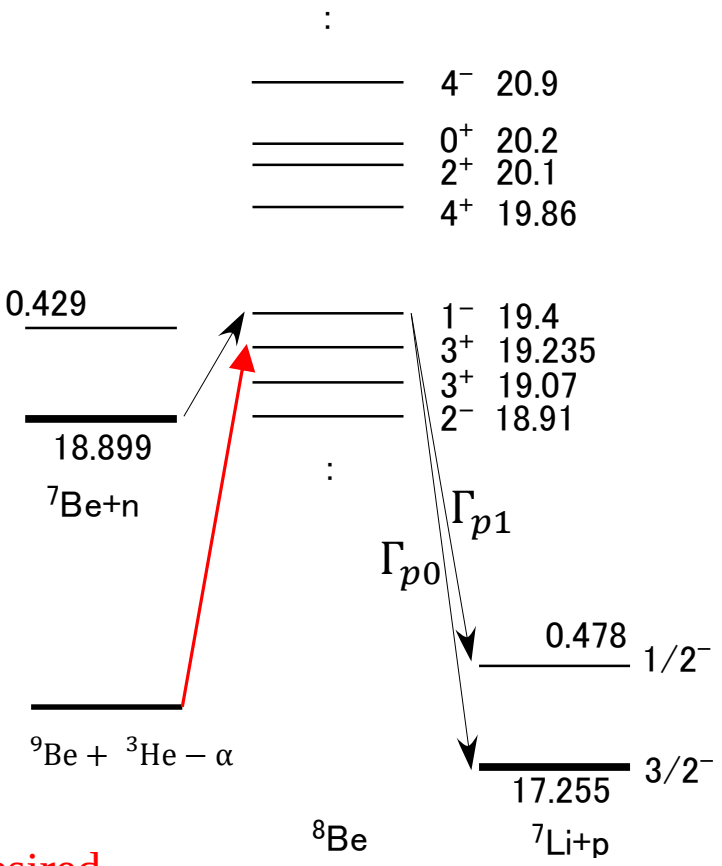
inverse reaction measurements (~2MeV)

⇒^{7}Be(n,p_1)^{7}Li* channel was completely neglected.

Recently, direct measurement of n_TOF up to 325keV was reported, however

35-40% larger cross section at low energy

^{7}Be(n,p_1)^{7}Li* was not evaluated separately

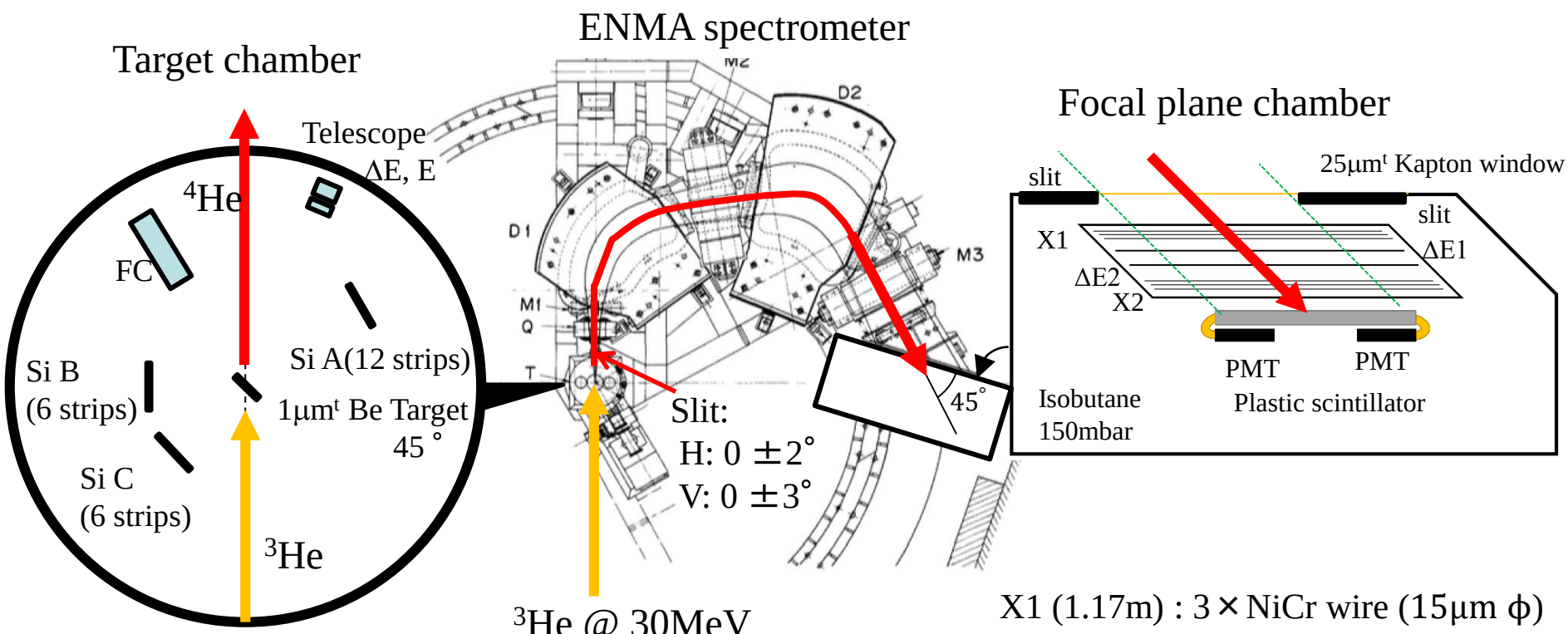


To deduce ^{7}Be(n,p_1)^{7}Li* reaction rate from inverse reaction data, experimental determination of Γ_{p1}/Γ_{p0} is desired.

We have performed ^{9}Be(^{3}He,α)^{8}Be(p)^{7}Li experiment. Resonant states in ^{8}Be were populated by the (^{3}He,α) reaction and decay protons were measured in coincidence with α.

Experimental Setup

◊ Tandem accelerator facility at Japan Atomic Energy Agency.



^{3}He @ 30MeV

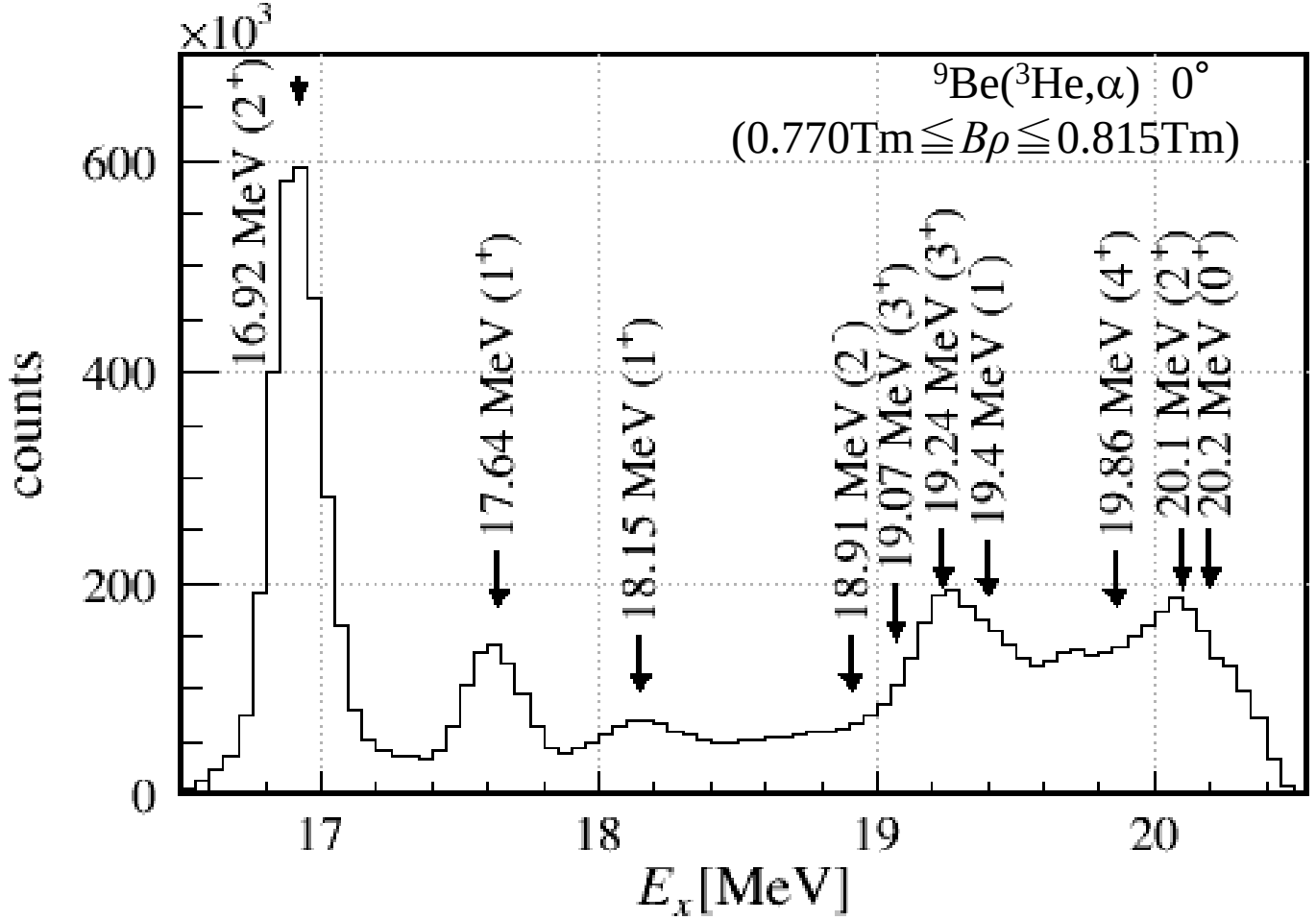
Si : 60 × 60 × 0.3 mm^3
Si-A: 150mm 48- 71°
Si-B: 120mm 76-104°
Si-C: 120mm 121-149°

Telescope 22.5°
8mmϕ 250mm
ΔE:0.15mm,
E:3mm

X1 (1.17m) : 3 × NiCr wire (15μm ϕ)
X2 (1.17m) : 3 × NiCr wire (15μm ϕ)
ΔE1, ΔE2 : Au-W wire (25μm ϕ)
Plastic Scintillator + 2 × PMT
HV: cathode: -800V, X1: 950V,
X2: 950V, ΔE1: 750V, ΔE2:750V

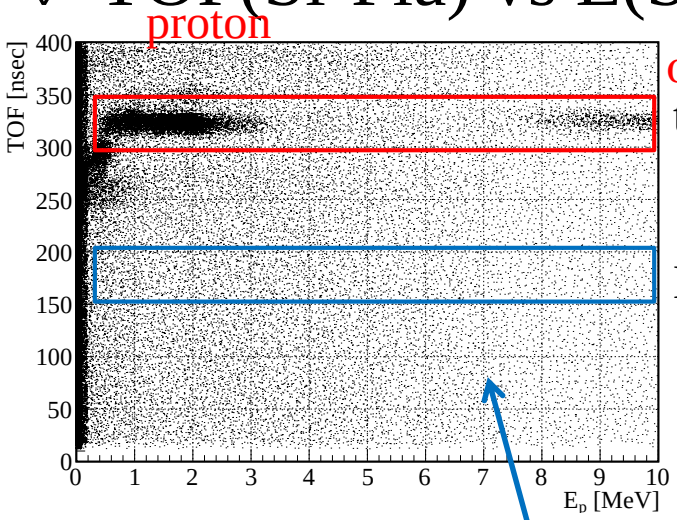
Excitation energy spectrum populated by the ^{9}Be(^{3}He,α)^{8}Be reaction

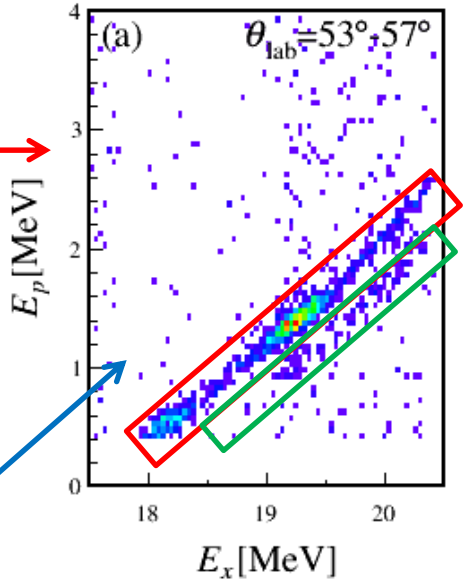
- Excitation energy spectrum of ^{8}Be populated by the ^{9}Be(^{3}He,α) reaction. It is deduced from $B\rho$ of α particles measured by the focal plane detectors.
- Known resonant states in ^{8}Be were indicated by the arrows.

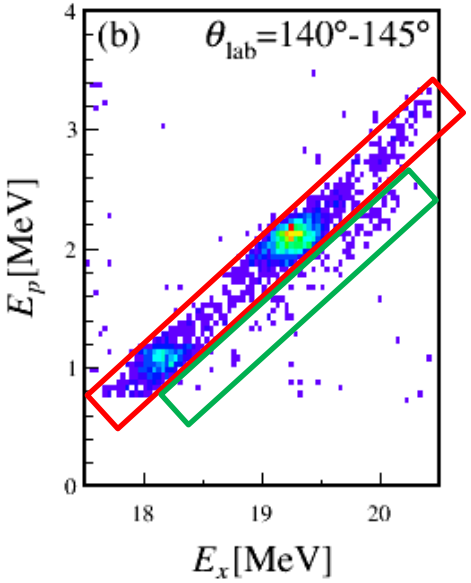


decay protons measured in coincidence

◊ TOF(Si-Pla) vs E(Si)







Accidental-coincidence-event subtraction: true-BG

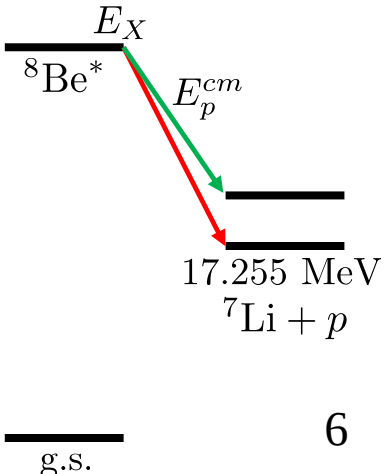
E_x: 100keV bin

30MeV ^{4}He ⇌ ^{4}He ~30MeV

^{8}Be* ~0.8MeV

180±20°

$$E_p^{lab}, \theta_p^{lab}, \frac{d^3\sigma^{lab}}{d\Omega^2 dE_x} \rightarrow E_p^{cm}, \theta_p^{cm}, \frac{d^3\sigma^{cm}}{d\Omega^2 dE_x}$$



Angular correlation

Strips were grouped

$\theta_1 = 59 - 70°$ (SiA 1-6)

$\theta_2 = 48 - 59°$ (SiA 7-12)

$\theta_3 = 90 - 104°$ (SiB 4-6)

$\theta_4 = 122 - 136°$ (SiC 1-3)

$\theta_5 = 136 - 150°$ (SiC 4-6)

E_x =19.15-19.25MeV

E_x =19.75-19.85MeV

$^7\mathrm{Li}_{gs}+p_0$

$^7\mathrm{Li}^*_{1st}+p_1$

Fitted by Legendre polynomials

$$\frac{d^3\sigma^{cm}}{d\Omega_\alpha d\Omega_p dE_x} = \sum_{L=0}^{l_{max}=3} A_L P_L(\cos\theta_p^{cm})$$

θ_p^{cm}[°]

θ_p^{cm}[°]

Integrated differential cross section over the solid angle of decay -protons was deduced

$$\frac{d^2\sigma^{cm}}{d\Omega_\alpha dE_x} = \int \sum_{L=0}^{l_{max}=3} A_L P_L(\cos\theta_p^{cm})\, d\Omega_p$$

Uncertainty stemming from assumption of l_{max} was estimated to be less than 10%.

Excitation energy spectra populated by the $^{9}Be(^{3}He,\alpha)^{8}Be$ reaction

◊ Large p_1 contribution was observed around 18.9MeV and 19.9MeV.

18.9 MeV: direct method: $\Gamma_{p1}/\Gamma_{p0} \sim 0.01$

larger p_1 contribution than that measured by the direct method

19.2 MeV: strong peak

small p_1 contribution

19.86 MeV: large p_1 contribution.

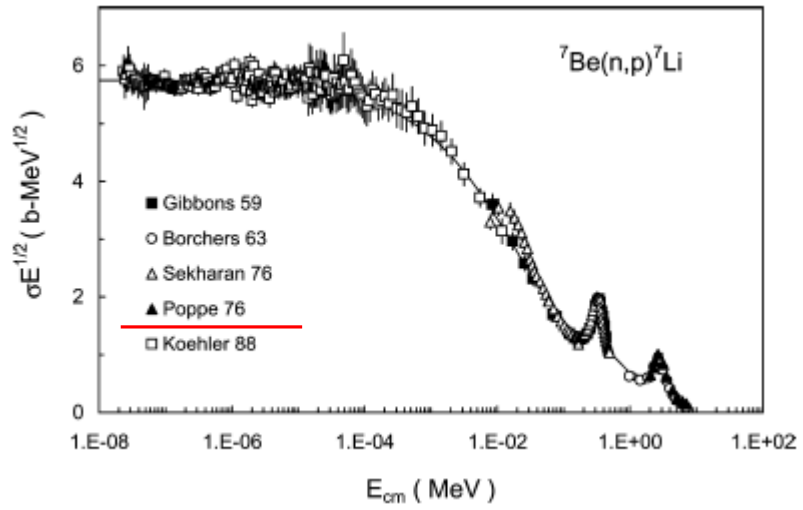
$^{8}Be \rightarrow p_0 + {}^{7}Li_{gs}$

S_n

$^{8}Be \rightarrow p_1 + {}^{7}Li^{*}_{1st}$

$\sigma(p_1 + {}^{7}Li^{*})/\sigma(p_0 + {}^{7}Li_{gs})$

P. Descouvemont et al. / Atomic Data and Nuclear Data Tables 88 (2004) 203–236



Summary

- The ^{9}Be(^{3}He,α)^{8}Be(p)^{7}Li reaction has been studied to study contribution of ^{7}Be-destruction channel ^{7}Be(n,p_1)^{7}Li* in cosmological lithium problem.
- It is first time to measure proton decay to the first excited state of ^{7}Li in wide energy range.
- Large p_1 contribution was observed in the resonances around 18.9 and 19.86MeV.
- The ^{7}Be(n,p_1)^{7}Li* reaction plays important role, but large ambiguity exists in the ^{7}Be(n,p_0)^{7}Li$_{gs}$ channel to deduce Γ_{p1}/Γ_{p0}.
- More accurate data (especially for ^{7}Li+p_0) are necessary to deduce precise Γ_{p1}/Γ_{p0}