Role of the ^{7}Be(n, p_1)^{7}Li* Reaction in the Cosmological Lithium Problem Studied with the ^{9}Be(^{3}He, α)^{8}Be*(p)^{7}Li Reaction

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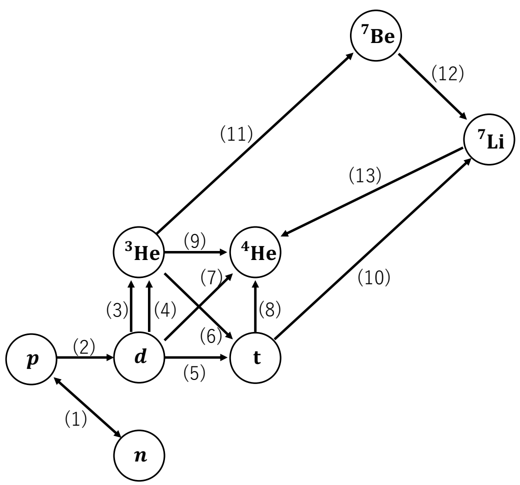
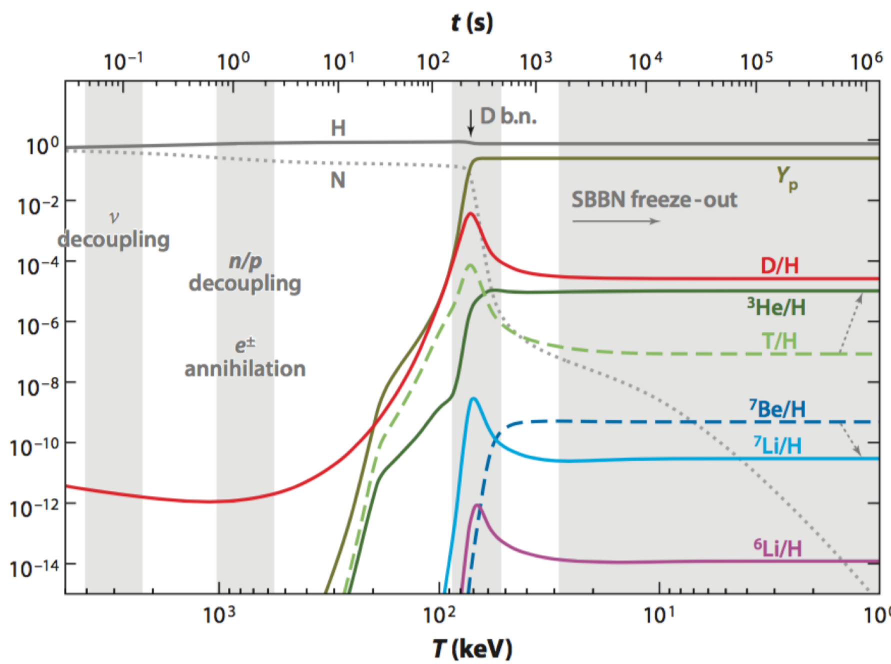
Contents

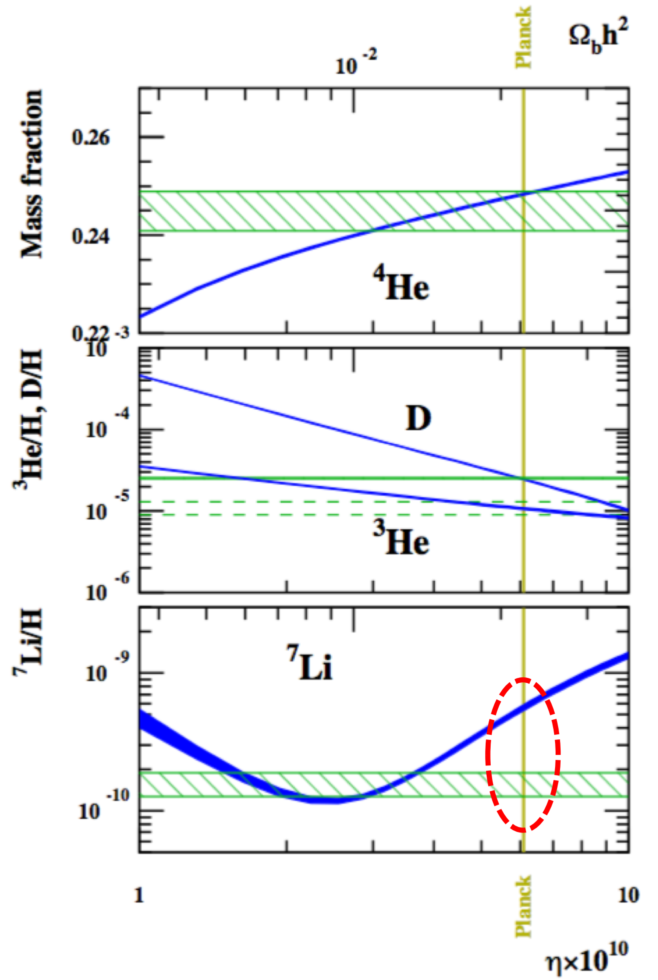
Motivation

- Big Bang Nucleosynthesis (BBN) model vs. observation
- Large discrepancy for ^{7}Li: Cosmological Lithium Problem
- $t(\alpha,\gamma)^7$Li followed by ^{7}Li$(p,\alpha)^4$He
- ^{3}He$(\alpha,\gamma)^7$Be $\xrightarrow{EC}$ ^{7}Li
- Decrease in ^{7}Be abundance during BBN may solve the problem.





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



A. Coc, arXiv:1707.01004v1 [astro-ph.CO]

Motivation

- Production: $^{3}\mathrm{He}(\alpha,\gamma)^{7}\mathrm{Be}$
- Destruction: neutron induced reaction

$\mathbf{^{7}Be}(n,p)\mathbf{^{7}Li}$ → direct measurement up to 13.5 keV

→ inverse reaction measurements

⇒ $^{7}\mathrm{Be}(n,p_1)^{7}\mathrm{Li}^{*}$ was ignored!

Controversial points in n_TOF data (up to 325 keV)

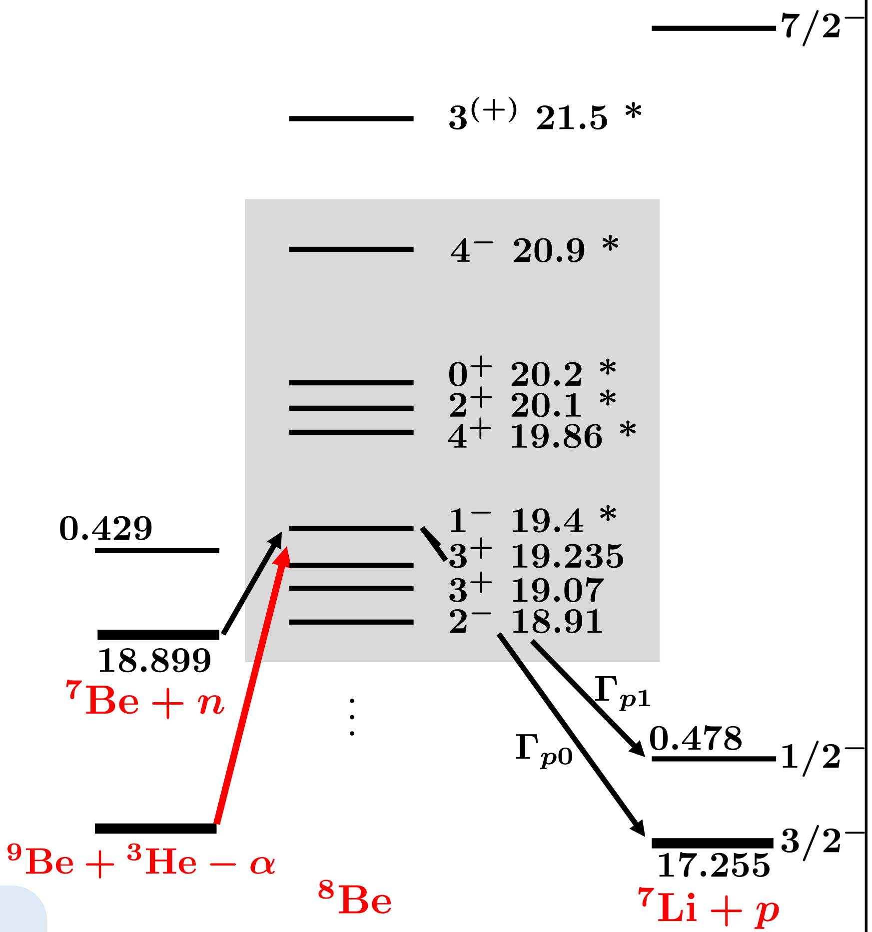
- 35% larger cross section at low energy.
- Angular distribution was not measured.
- $^{7}\mathrm{Li}^{*}+p_1$ not evaluated separately.
- $<\sigma v>$ was deduced using (p,n) data.

Objective:

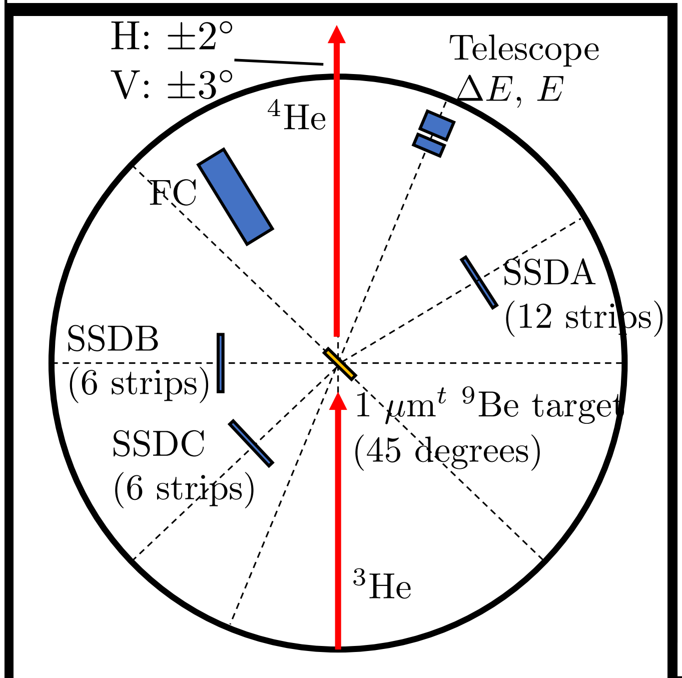
$^{7}\mathrm{Be}(n,p_1)^{7}\mathrm{Li}^{*}$ cross section using the inverse reaction data

⇒ **Experimental determination of Γ_{p1}/Γ_{p0} is required!**

We carried out the $^{9}\mathrm{Be}(^{3}\mathrm{He},\alpha)^{8}\mathrm{Be}^{*}(p)^{7}\mathrm{Li}$ reaction measurement at 30 MeV to deduce the branching ratio for the resonance states of $^{8}\mathrm{Be}$ at 18.91-20.2 MeV.



Experimental Setup

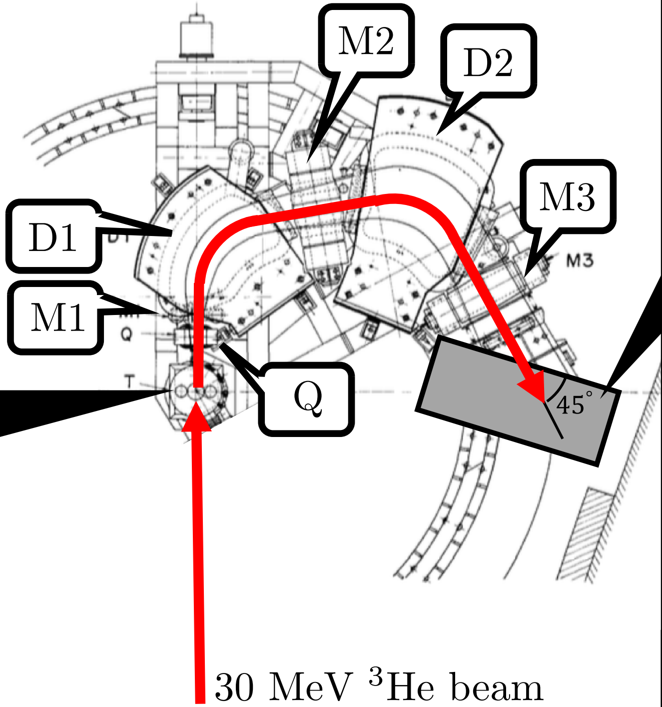


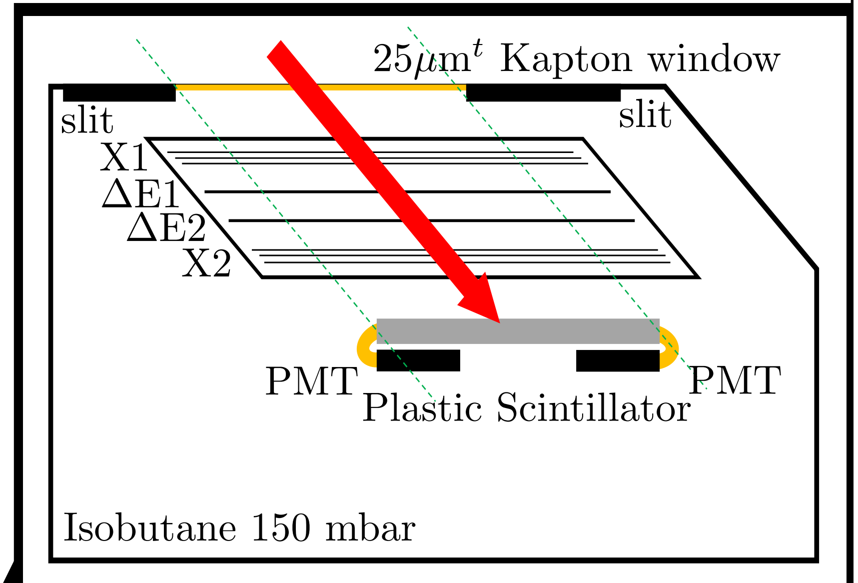
Target Chamber

- SSD: $60 \times 60 \times 0.3$ mm^3
- SSDA: 150 mm, 48-71°
- SSDB: 120 mm, 76-104°
- SSDC: 120 mm, 121-150°
- Telescope: 22.5°, 8 mmϕ
  ΔE : 0.15 mm^t, E : 3 mm^t

Magnetic Spectrometer ENMA

- Q-M-D-M-D-M ststem
- $(x|x) = 1.7$
- $(x|\delta) = 12.6$ cm/%





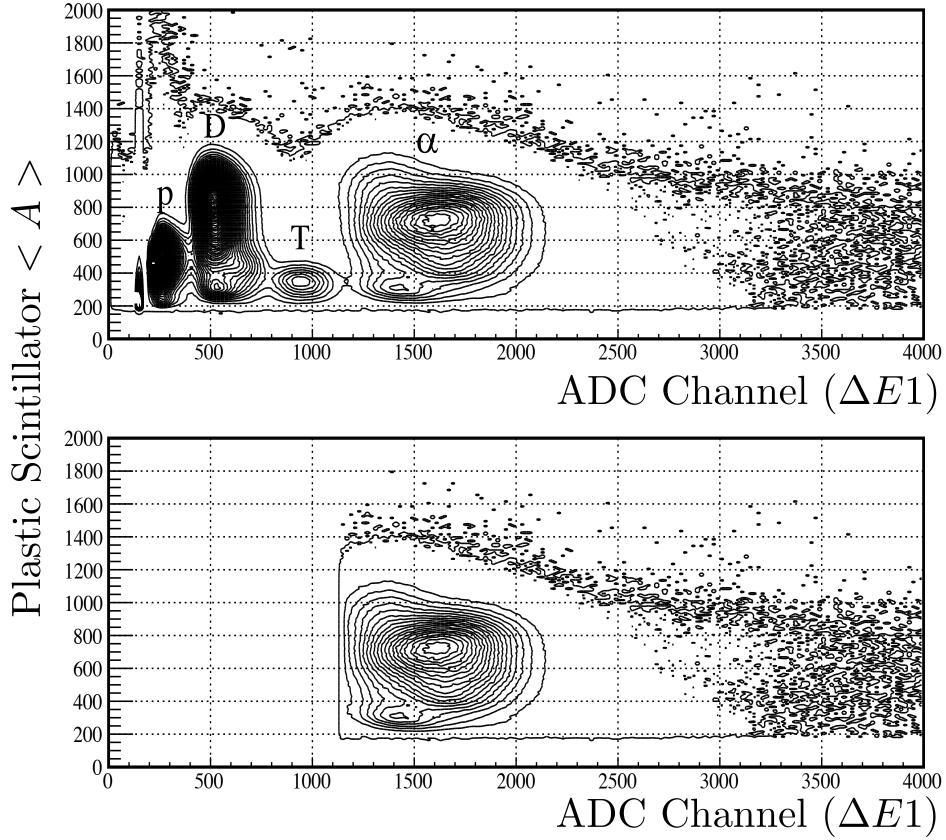
Focal Plane Chamber

- X1 (1.17 m): 3×NiCr wire(15 $\mu m\phi$),2.2 kΩ
- X2 (1.17 m): 3×NiCr wire(15 $\mu m\phi$),2.2 kΩ
- ΔE1, ΔE2: Au-W wire(25 $\mu m\phi$)
- Plastic Scintillator+2×PMT
- HV:
  Cathode=-800 V
  X1=950 V, X2=950 V
  ΔE1=750 V, ΔE2=750 V

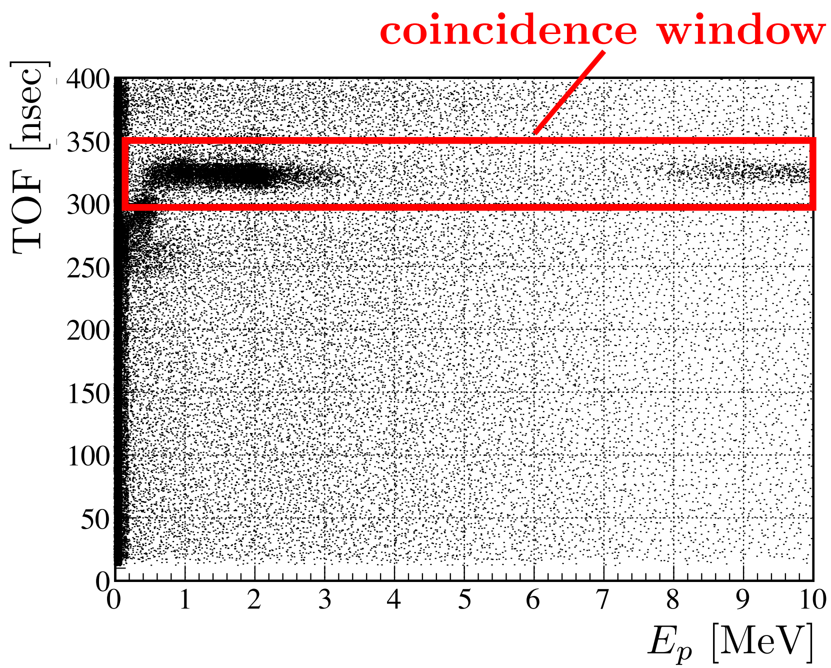
Particle Identification

the ^{9}Be(^{3}He, α)^{8}Be*(p)^{7}Li reaction measurement

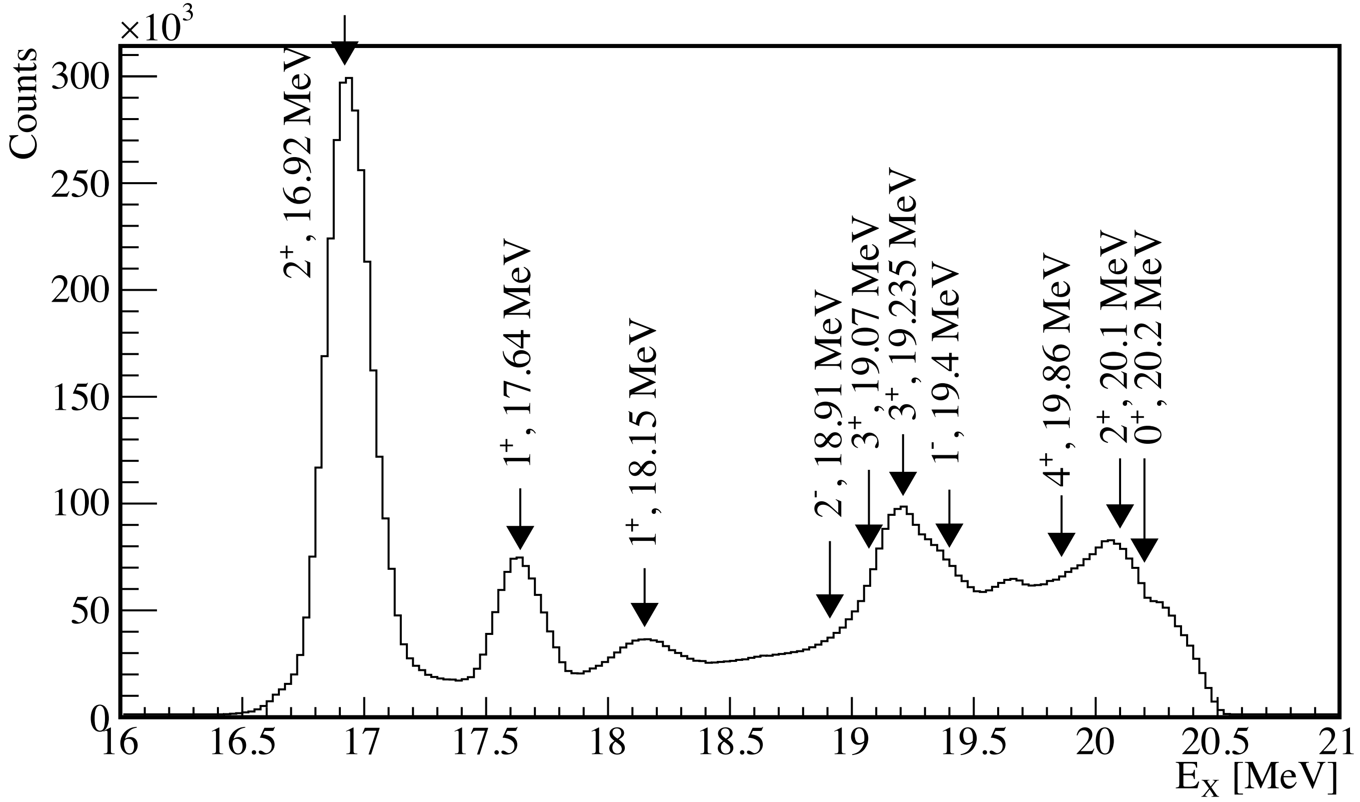
ΔE-E at the focal plane chamber $(0.770 \leq B\rho \leq 0.815)$

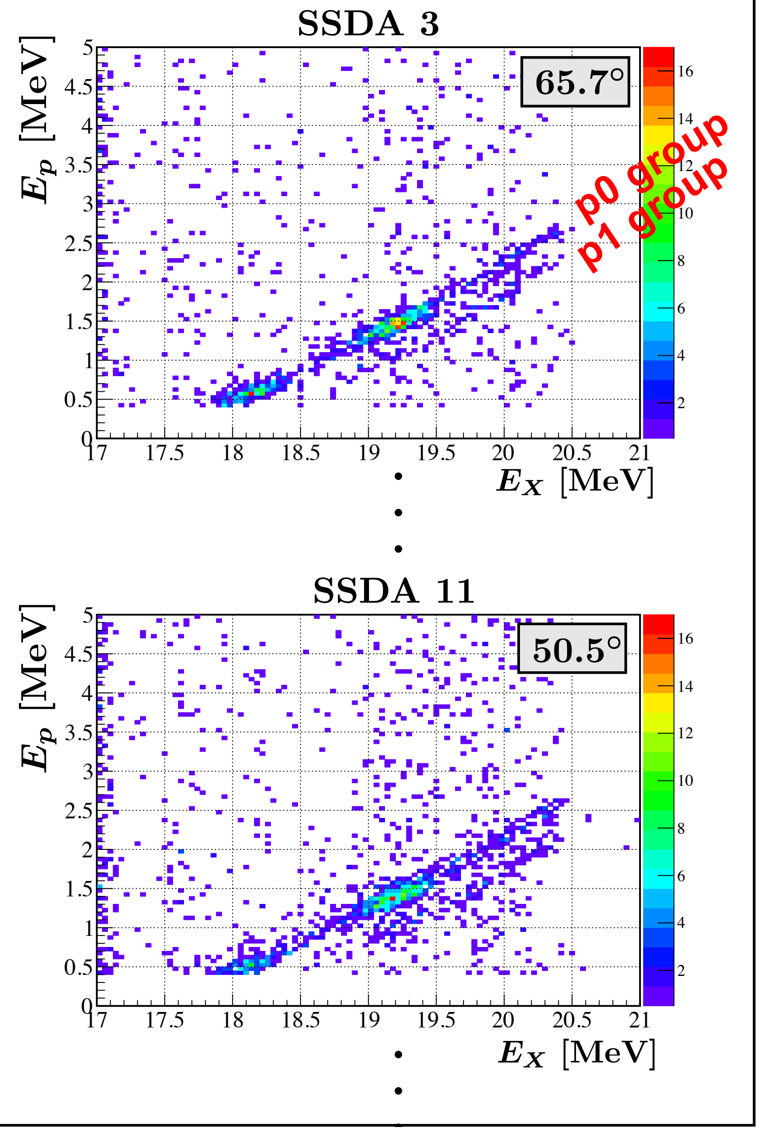


E-ToF at SSD



Excitation Energy Spectrum of ^{8}Be





Reconstruction

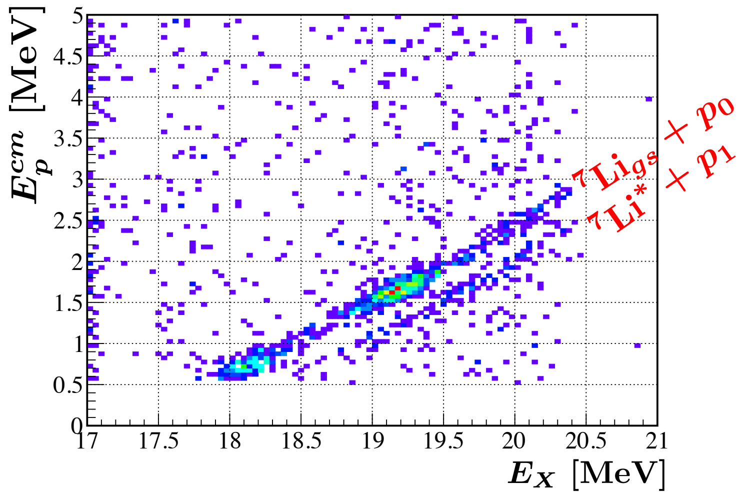
Two-Body Kinematics

- Reaction (^{9}Be + ^{3}He $\to$ ^{8}Be* + α)
- Sequential Decay (^{8}Be* $\to$ ^{7}Li + p)

^{8}Be recoils at $180° \pm 20°$ with $E \simeq 0.2$ MeV

$$E_p^{cm} = \frac{1}{2} m_p c^2 \{ \left(\beta_p^{lab} \cos\theta_p^{lab} - \beta_G \right)^2 + \left(\beta_p^{lab} \sin\theta_p^{lab} \right)^2 \}$$

$$\theta_p^{cm} = \tan^{-1} \left(\frac{\sin\theta_p^{lab}}{\cos\theta_p^{lab} - \beta_G^{lab}/\beta_p^{lab}} \right)$$



Differential cross section in the rest frame of ^{8}Be!

$$\left(\frac{d^3\sigma}{dE_X d\Omega_\alpha d\Omega_p} \right)^{cm} = \frac{|1 + \gamma \cos\theta_p^{cm}|}{(1 + 2\gamma\cos\theta_p^{cm} + \gamma^2)^{3/2}} \times \left(\frac{d^3\sigma}{dE_X d\Omega_\alpha d\Omega_p} \right)^{lab}$$

$$\gamma = \beta_G / \beta_p^{cm}$$

Angular Distribution

Fit with a series of Legendre polynomials up to 3rd order

$$\left(\frac{d^3\sigma}{d\Omega^2 dE_X}\right)_{cm} = \sum_{L=0}^{3} A_L P_L(\cos\theta_p^{cm})$$

where

$$P_0 = 1$$

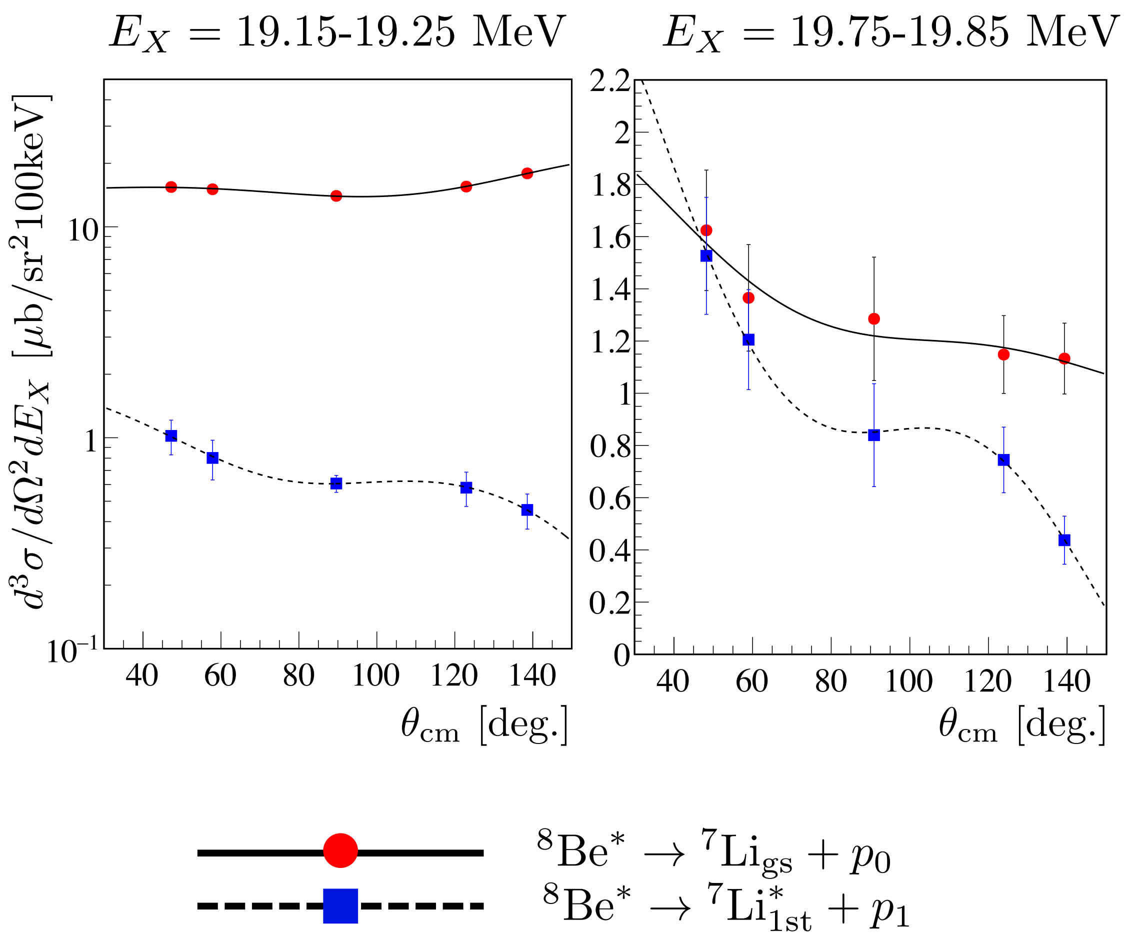
$$P_1 = \cos\theta_p^{cm}$$

$$P_2 = \frac{1}{2}(3\cos^2\theta_p^{cm} - 1)$$

$$P_3 = \frac{1}{2}(5\cos^3\theta_p^{cm} - 3\cos\theta_p^{cm})$$

then,

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



(a) ^{9}Be(^{3}He, α)^{8}Be*(p_0)^{7}Li$_{gs}$ reaction

(b) ^{9}Be(^{3}He, α)^{8}Be*(p_1)^{7}Li$^*_{1st}$ reaction

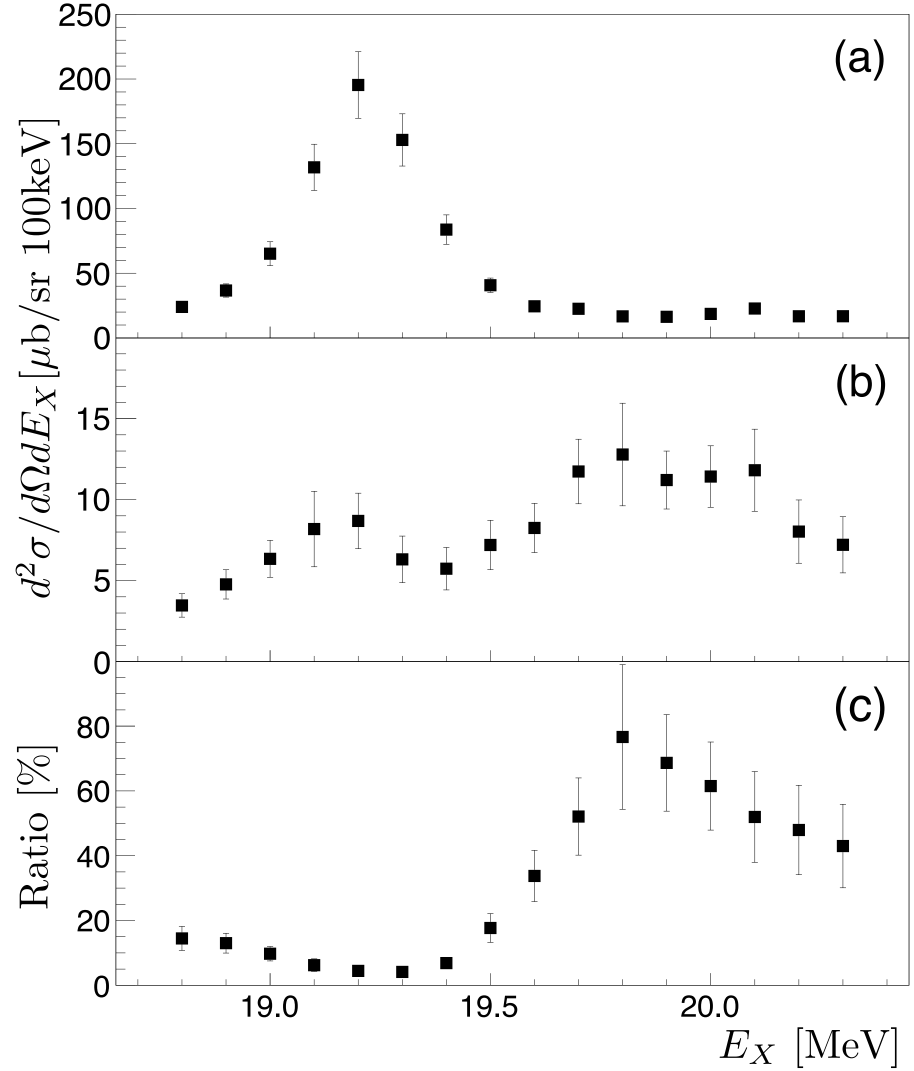
(c) the ratio of data in (b) to the ones in (a)

Ratio is:

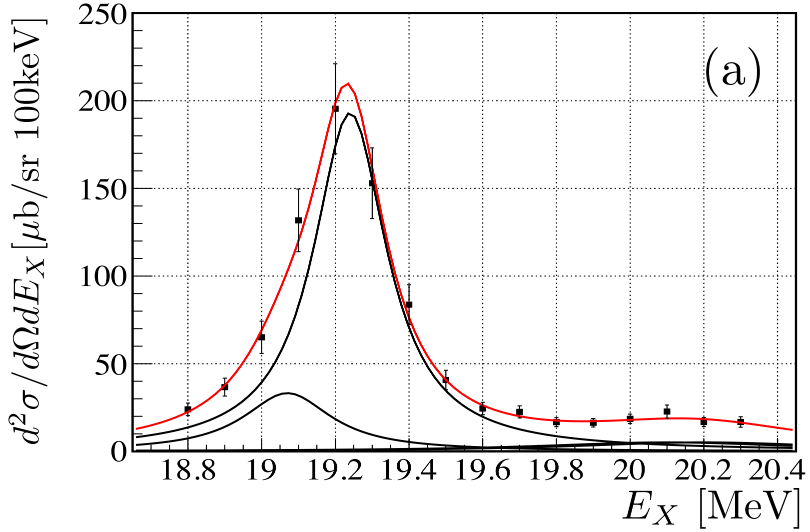
about 10% around 18.9 MeV.
→near 2^-(18.91 MeV) resonance
→much larger than the prior results (≃1%)
→truly a large Γ_{p1}/Γ_{p0}?
→a new resonance state below 18.91 MeV?

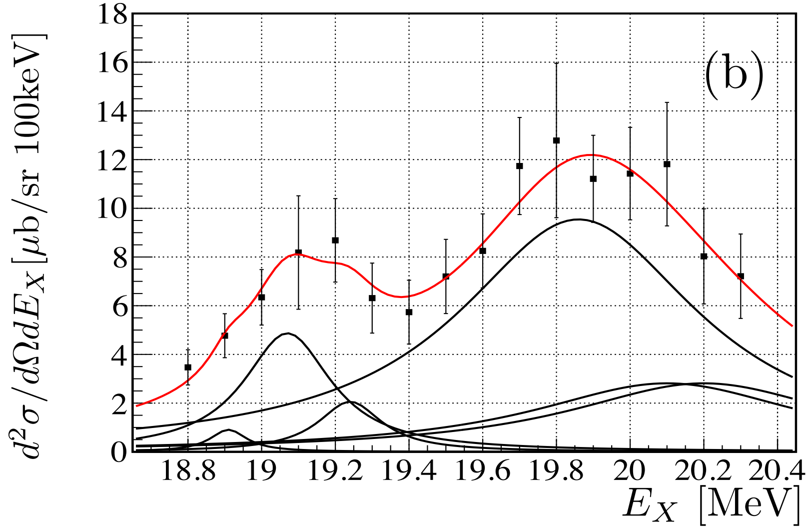
about 5% around 19.2 MeV.
→near 3^+(19.235 MeV) resonance
→small at the important energy region in BBN.

about 80% around 19.8 MeV.
→large contribution at the 19.86 MeV resonance.



Resonance Fit Results





SLBW (18.91 - 20.2 MeV) fit

Preliminary Results

E_X [MeV]	J^π	Γ_{p1}/Γ_{p0}	$\Gamma_{p1}/(\Gamma_{p0}+\Gamma_{p1})$ [%]
18.91	$\mathbf{2^-}$	$\mathbf{2.32\times10^{9}\pm5.73\times10^{18}}$	**100±139**
19.07	3^+	$1.27\times10^{-1}\pm2.97\times10^{-2}$	11.3±2.6
19.235	$\mathbf{3^+}$	$\mathbf{1.33\times10^{-2}\pm5.38\times10^{-3}}$	**1.3±0.5**
19.4	1^-	$1.69\times10^{-4}\pm5.84\times10^{-1}$	0.01±58
19.86	$\mathbf{4^+}$	$\mathbf{2.09\times10^{8}\pm6.49\times10^{15}}$	**100±37**
20.1	2^+	$1.44\times10^{-1}\pm4.44\times10^{-1}$	12.6±38.6
20.2	0^+	$1.92\times10^{-1}\pm1.06\times10^{-1}$	16.1±8.6

- Large p1 contribution at 18.91 and 19.86 MeV resonance states.
- Small contribution at 19.235 MeV.

Conclusions and Perspectives

- The ^{9}Be(^{3}He, α)^{8}Be*(p)^{7}Li reaction measurement to deduce the Γ_{p1}/Γ_{p0} ratio for each of the resonance states of ^{8}Be.
- Succeeded in measuring the $^{7}\mathrm{Li}^{*} + p_1$ events!
- Large ratios were found around $E_X = 18.91$, 19.86 MeV.
- Small ratio around the most important energy region ($E_X = 19.235$ MeV), suggesting that the ^{7}Be(n, p_1)^{7}Li* reaction cross section may not solve the lithium problem.
- Systematic errors.
- Resonance fit should be more rigorous. Then, evaluate the reaction rate $< \sigma v >$ and run the BBN calculation!
- Need to improve the statistical accuracy→Additional beam time!