Bose Institute

Search for higher excited states of $^{8}Be^{*}$ to study the cosmological ^{7}Li problem

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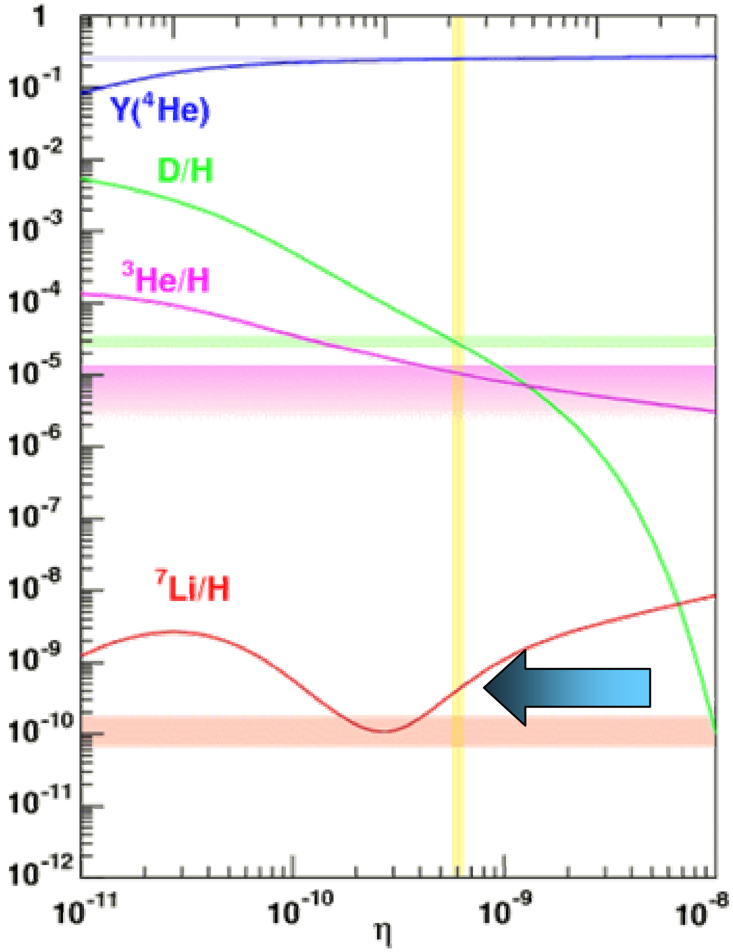
INTC Meeting, CERN, November 1, 2012

Physics case



Observed values represented by bands, predicted values represented by lines.

$\eta_b^{WMAP} = n_B/n_\gamma = (6.23 \pm 0.17) \times 10^{-10}$

ratio of the baryon and photon number densities

Serious discrepancy of a factor of about 4 in primordial ^{7}Li abundance, while good agreement of D, ^{3,4}He abundances

BBN theory using η_b^{WMAP}: $^7\mathrm{Li/H} = 5.12\,_{-0.62}^{+0.71} \times 10^{-10}$

Observationally extracted: $^7\mathrm{Li/H} = 1.23\,_{-0.16}^{+0.34} \times 10^{-10}$

The Cosmological ^{7}Li problem

Aim of the experiment:

Study discrepancy of ^{7}Li abundance in the context of **resonance enhancement** of nuclear reactions

Importance:

One of the **important unresolved problems** of present-day astrophysics.

Existing data: nuclear/astrophysical/new effects beyond standard BBN- inconclusive

Incomplete nuclear physics input for BBN calculations: Can resonant enhancement alleviate this discrepancy?

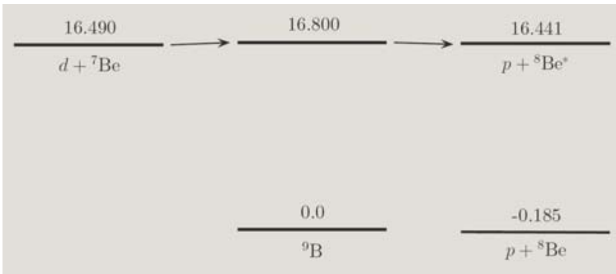
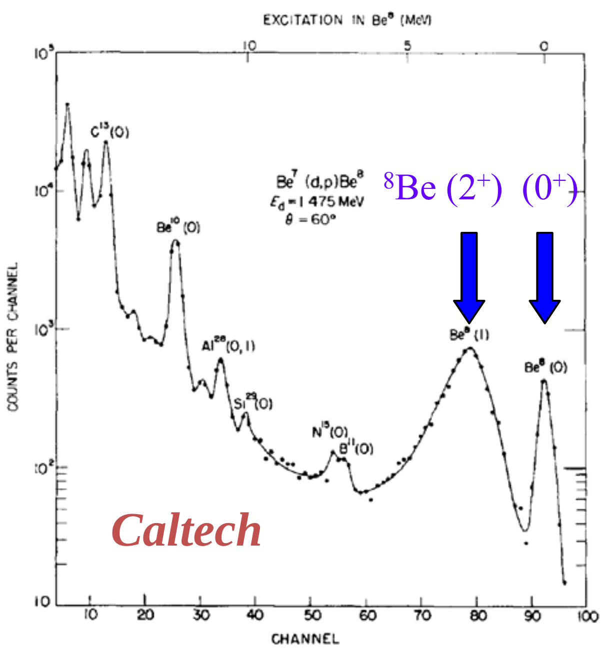


FIG. 1. Schematic illustration of the proposed ^{7}Be destruction mechanism, $d+{}^7\mathrm{Be}\rightarrow{}^9\mathrm{B}^*\rightarrow p+{}^8\mathrm{Be}^*$. The energies are in MeV relative to the ground state of ^{9}B. Subsequently, ^{8}Be* breaks up into two α particles.

^{7}Li mostly produced as ^{7}Be during Big Bang. One narrow nuclear level in ^{9}B, $E_{5/2+}\approx 16.7$ MeV, not sufficiently studied experimentally, and just ~ 200 keV above the ^{7}Be+d threshold, may lead to resonant enhancement of ${}^7\mathrm{Be}(d,\gamma){}^9\mathrm{B}$ and ${}^7\mathrm{Be}(d,p){}^8\mathrm{Be}$ reactions.

Cyburt et al
arXiv:0906.4373v1 (2009)



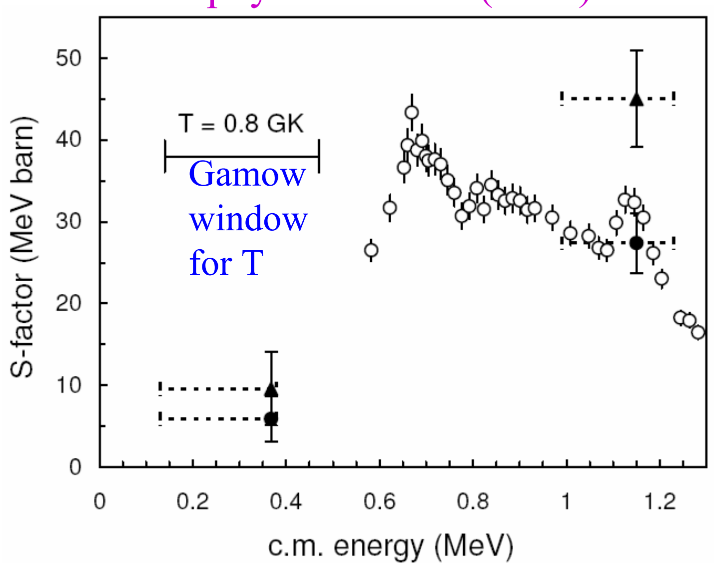
${}^7\mathrm{Be}(d,p){}^8\mathrm{Be}^*\rightarrow 2\alpha$ (Q = 16.490 MeV)

R. W. Kavanagh
Nuclear Physics 18 (1960) 492

upto E_x= 11 MeV

E_{cm} = 0.6 – 1.3 MeV, reaction rate relied on an extrapolation to BBN energies. Differential cross section multiplied by 4π (assuming isotropic angular distribution) and arbitrarily by 3 (to estimate contribution of higher energy ^{8}Be states)

Angulo et al
Astrophys. Jour. 630 (2005) L105



^{7}Be(d,p)^{8}Be*→2α (Q = 16.490 MeV)

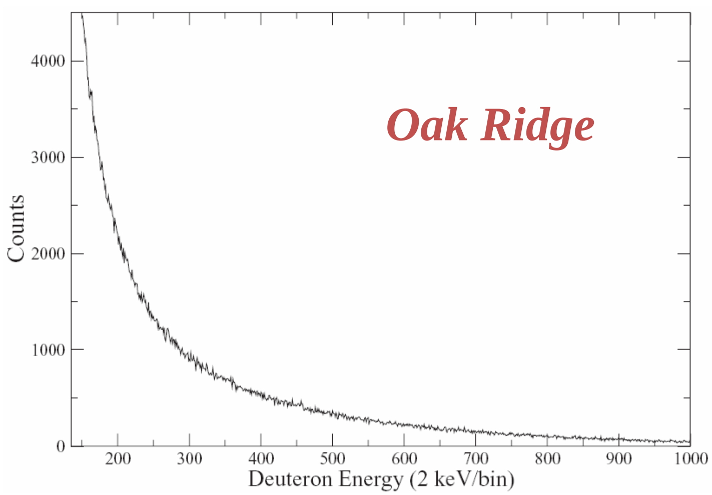
(E_{7Be}= 5.55, 1.71 MeV) **upto E_x= 13.8 MeV**

- ○ Kavanagh (1960)
- ● Angulo (2005), ^{8}Be* (g.s + 1st ex.s)

Cross section overestimated previously

Due to Coulomb barrier, contributions of the higher states were negligible. Small angular range covered (~ 7-17 deg) and full isotropy for proton angular distribution **assumed** in calculating average cross section

O'Malley et al
Phys. Rev. C 84, 042801(R) (2011)

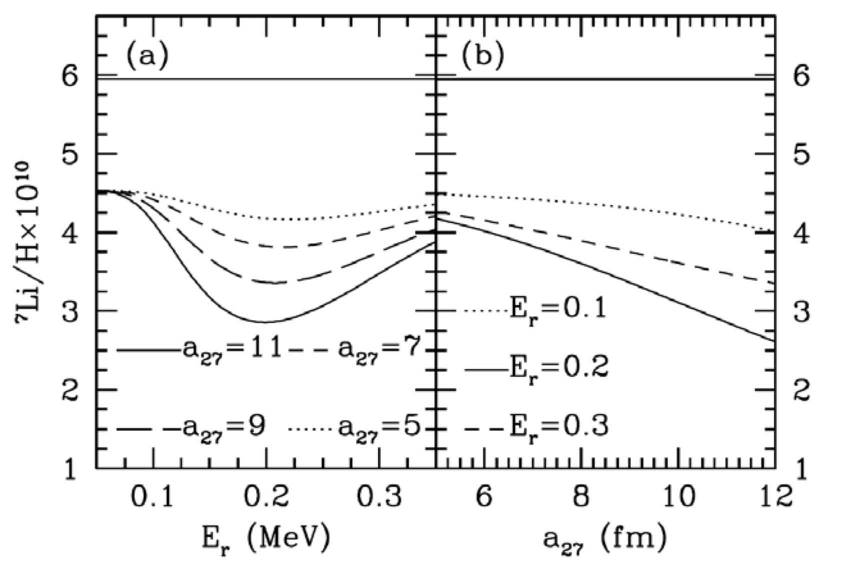


Resonance enhancement of the ^{7}Be(d,p)2α reaction through the 5/2^{+} 16.7 MeV resonance state in ^{9}B ? ^{2}H(^{7}Be,d)^{7}Be (E_{7Be}= 10 MeV)

No evidence for a resonance observed

Clearly more study of possible resonances in ^{7}Be + d reactions and the 16.7 MeV state in ^{9}B needed. This state has the potential to significantly influence ^{7}Be destruction.

Cyburt et al
arXiv:0906.4373v1 (2009)



Reaction rates of the ^{7}Be destruction by deuterons could be large, owing to a narrow resonance 16.7 MeV ($5/2^+$) in ^{9}B. **This resonance may be very strong**, and at the very limit of the quantum mechanically allowed value for the deuteron separation width. This would be responsible for a factor of ~ 2 suppression of the primordial ^{7}Be yield, ***resolving ^{7}Li problem***.

(Resonant energy E_r, deuterium separation width Γ_d) **≈ (170-220, 10-40) keV** can **eliminate current discrepancy**. Such a large width at this resonant energy can only be achieved if the interaction radius for the deuterium entrance channel is very large, $a_{27} \geq 9$ fm

Chakraborty et al
Phys. Rev. D 83, 063006 (2011)

16.7 MeV ($5/2^+$) in ^{9}B, a large channel radius (a>10 fm) needed to give sufficiently large widths

Quantum mechanics could allow resonant properties that can remove or substantially reduce the lithium discrepancy.

Merit of the experiment

Measurements of the 16.7 MeV (5/2+) resonance in ^{9}B at HIE-ISOLDE offering higher beam energies and intensity of ^{7}Be can resolve the 7Li issue. Direct experimental information about its p and α decay properties unknown. Dominated by a single proton-decay branch to the 16.626 MeV (2+) state in ^{8}Be ?

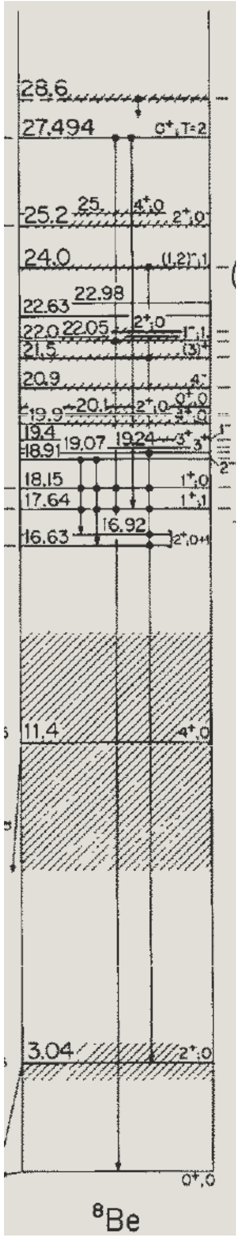
FIRST TIME

higher beam energy : measure higher excitation energies in ^{8}Be up to about **20 MeV**

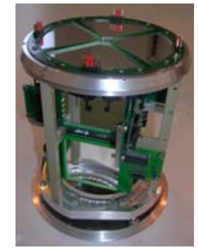
wider angular coverage : 5-50 deg, improved average cross section measurements without assuming isotropy done in earlier works

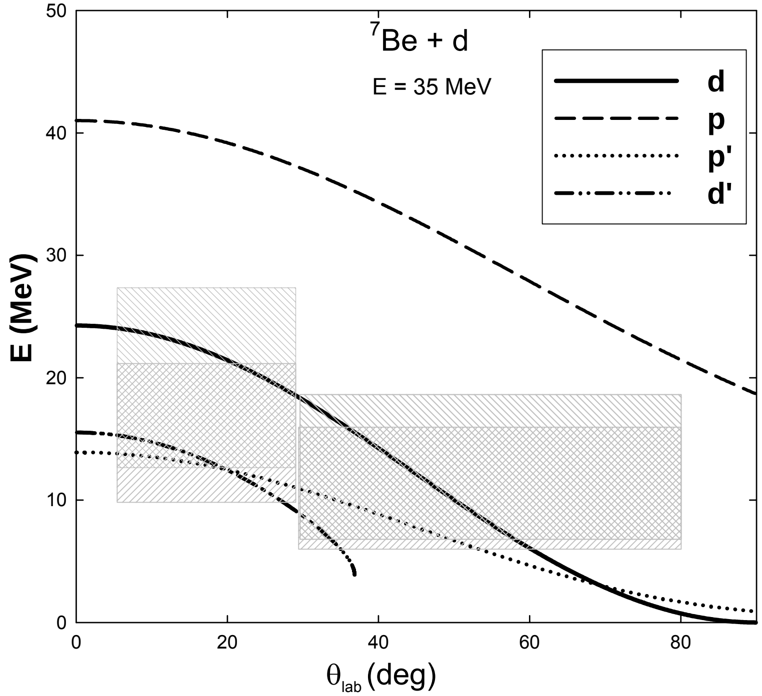
ONLY POSSIBLE AT HIE-ISOLDE (beam energy and intensity)

35 MeV ^{7}Be : measure (d,p) (d,d) with T-REX
CD_2 target of thickness 1 mg/cm^2, I = 10^8 pps
Estimated cross section ~ 500 mb
Expected count rate ~ 1000/s
Beamtime request: **15 shifts** of beam on target, 3 shifts for preparation.



Kinematics



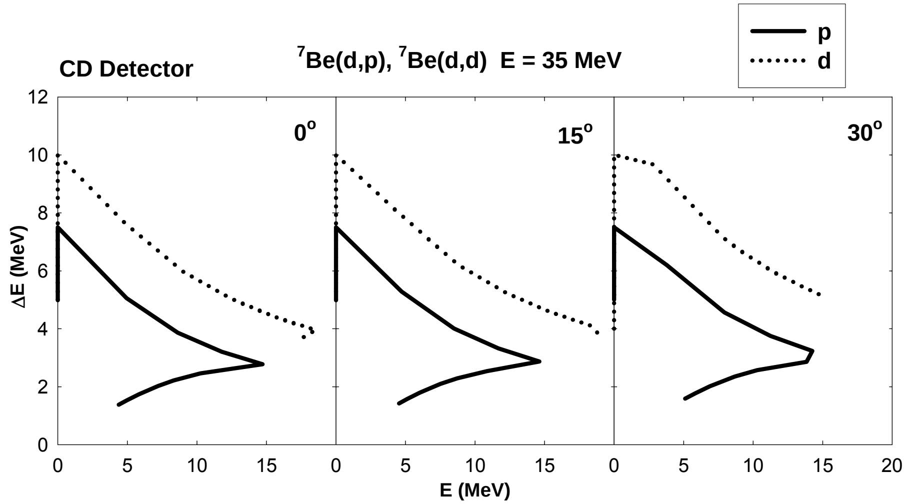


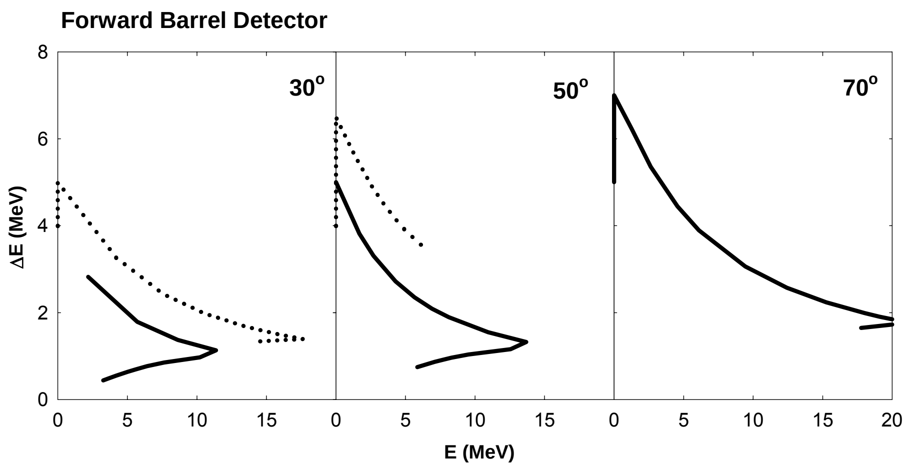
Kinematics of the 7Be(d,d), 7Be(d,p) reactions for ground state (d) (p), excitation of 20 MeV (p'), 5 MeV (d') respectively. The forward hashed (backward hashed) areas cover the detected p (d) energies and angles in CD and barrel detectors of T-REX.

CD (ΔE=500 μm, E = 1.5 mm), Forward Barrel (ΔE=140 μm, E = 1.0 mm)

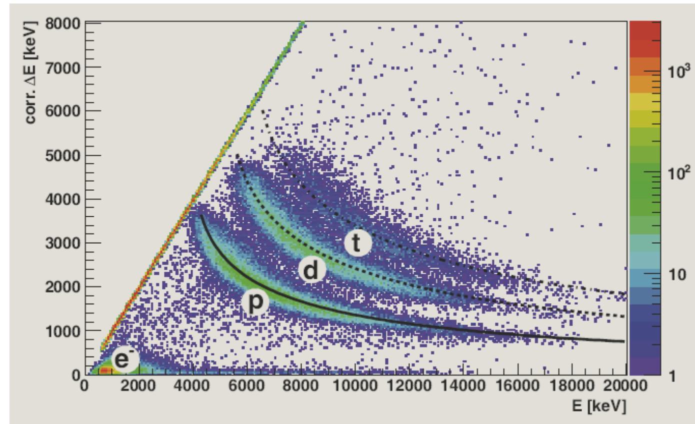
Protons : E_x =0, E_p = 20-40 MeV, do not stop

E_x =20 MeV, E_p = 4-14 MeV at 5 – 50 deg, corresponding α-particles stop in ΔE





Bildstein et al
Eur. Phys. J. A 48, 85 (2012)



Energy resolution of T-REX would be sufficient for particle identification in this experiment

Excitation energies of the populated states of interest can be reconstructed from deposited energies in various detectors for stopping particles. Breakup of $^{8}Be \rightarrow 2\alpha$ particles that stop in ΔE detectors of T-REX, can be identified by using a multiplicity trigger.

At ISOLDE, ^{7}Be is produced with very high yields and even with a modest charge breeding efficiency 2-3% we should get plenty of beam at the end of the linac. Energy should be well above 5.5 MeV/A for this A/q.

Concerning contaminations of the beam, both **^{14}N** and **^{21}Ne** can be **suppressed completely** by selecting $^{7}Be^{4+}$ after a stripping foil inserted at the end of the linac ($^{7}Be^{3+}$ being accelerated up to the stripper foil).

As the halflife is long we will not reach saturation for the radiation level during the run. There are no restriction from a radiation protection point of view. If (for example) we take 10^{8} pps for 3 x 8 h shifts we will end up with ~ 9×10^{12} ions collected which lead to an activity of 0.2 MBq. Regarding the radiological hazards of radioactive nuclei produced at ISOLDE, the activity we need for our experiment is only a very small fraction of the authorization limit LA (**very small internal exposure risk**).

The hazard related to **external exposure**, assessed via the h10 quantity which for ^{7}Be = 0.008 (mSv/h)/GBq at 1 m quantity which give the dose rate at 1 m per GBq of activity.

Outcome of the Experiment

•**Higher excitation energies in ^{8}Be -** measurement up to about **20 MeV** from (d,p)

•**Properties of the 16.7 MeV (5/2+) resonance in ^{9}B** from (d,d)

Direct experimental determination of corresponding reaction rates might either support/refute a nuclear physics solution to the lithium problem. Other effects may include astrophysical effects, new effects (beyond standard BBN model) or a combination of all. Conventional solutions to the lithium problem ask for experimental testing.

While astrophysical solutions are not ruled out, they are increasingly constrained. Thus a serious and thorough evaluation of all possible nuclear physics aspects of primordial lithium production is urgent in order to determine whether the lithium problem truly points to new fundamental physics.

•**Only possible at HIE-ISOLDE.**