Measurement of $^{7}Be(n,\alpha)$ and $^{7}Be(n,p)$ cross sections for the Cosmological Li problem in EAR2@n_TOF

Request for a test beam at n_TOF and sample preparation at ISOLDE

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Outline

- Physics Case

- ^{7}**Be(n,p)** measurement
- ^{7}**Be(n,α)** measurement

} Step 2 (addendum to this proposal)

- **Test measurement and sample preparation** ← Step 1(this proposal)

Big Bang Nucleosynthesis

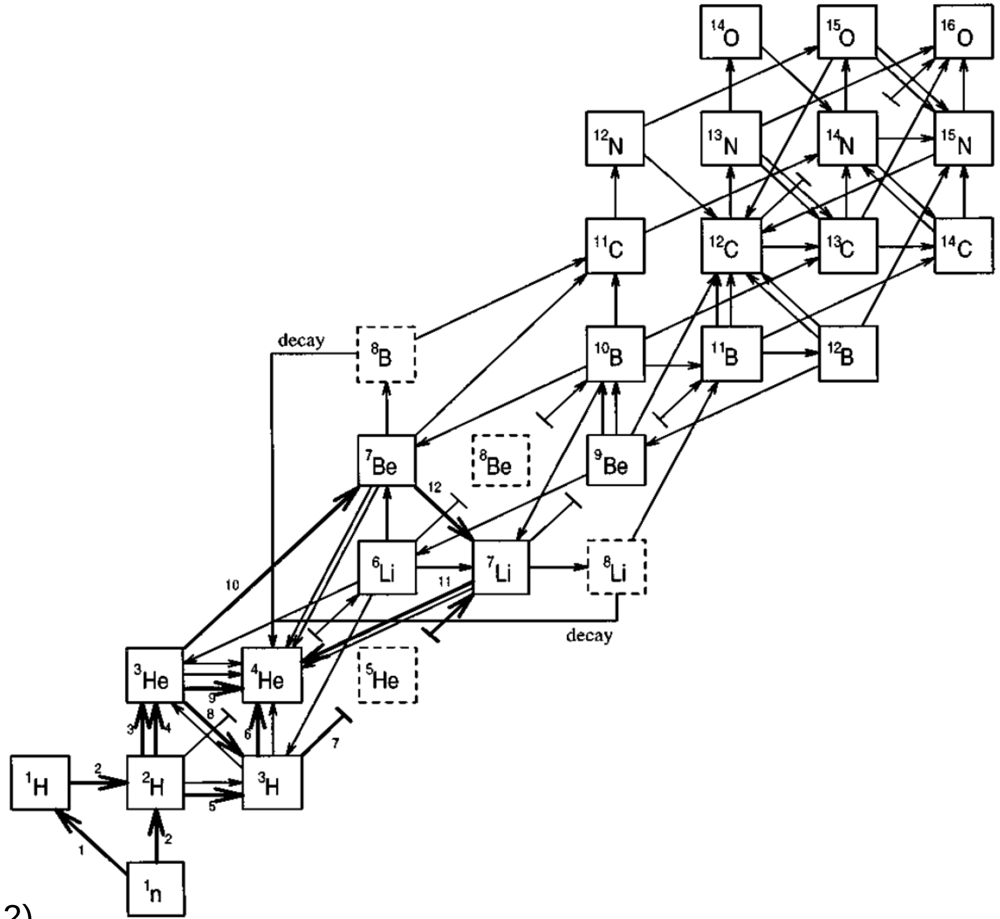
Big Bang Nucleosynthesis (BBN), together with Hubble expansion and Cosmic Microwave Background Radiation is one of the cornerstones for Big Bang Theory.

BBN gives the sequence of nuclear reactions leading to the synthesis of light elements up to Na* in the early stage of Universe (0.01-1000 sec)

At his first formulation, it depended on 3 parameters:

- -the baryon-to-photon ratio η,
- -the number of species of neutrino ν,
- -the lifetime of neutron τ.

Nowadays **BBN is a parameter free theory****, being the **cross-sections** of reactions involved the only input to the theory.



* A.Coc et al., The Astrophysical Journal, 744:158 (2012)

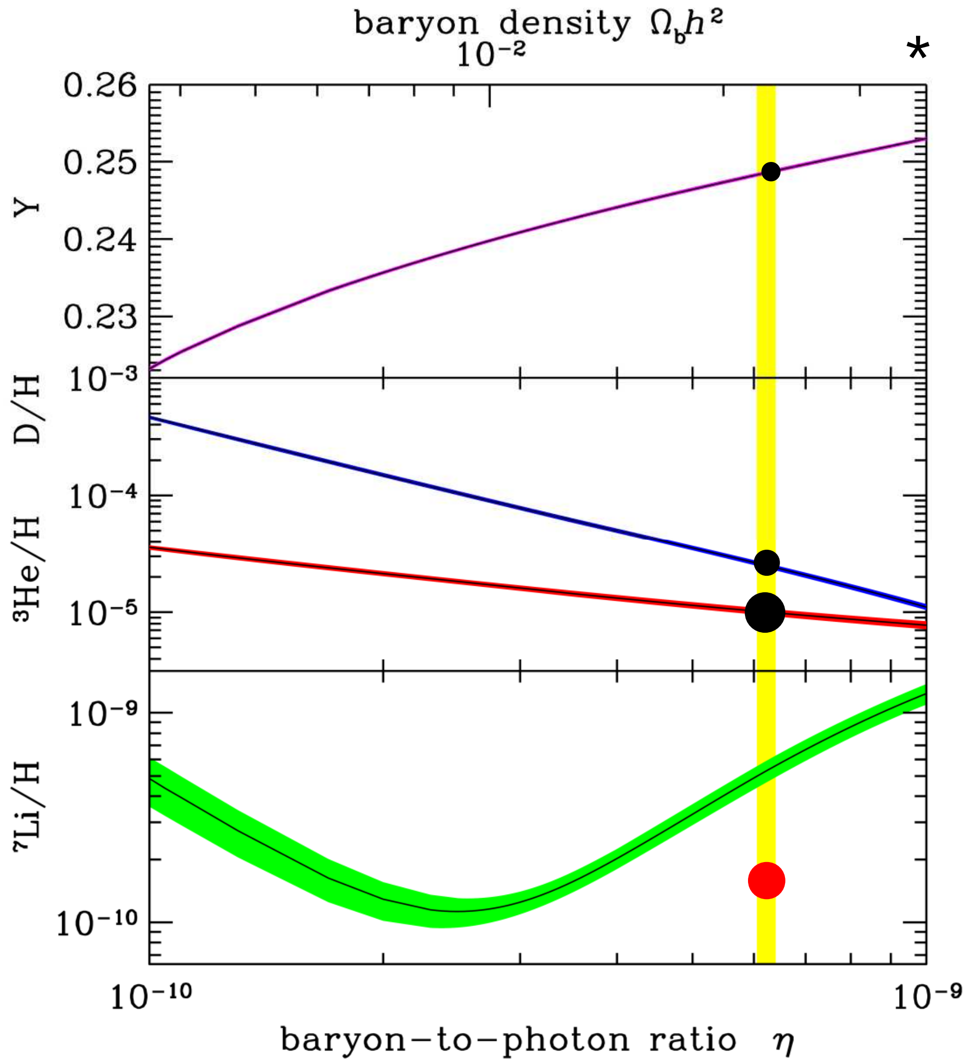
**D.N. Schramm and T.S Turner, Rev. Mod. Phys 70 (1998) 303

The Cosmological Lithium Problem

BBN successfully predicts the abundances of primordial elements such as ^{4}He, D and ^{3}He.

A serious discrepancy (factor 2-4) between the predicted abundance of **^{7}Li** and the value inferred by measurements (Spite et al, many others.)

Cosmological Lithium Problem (CLiP)

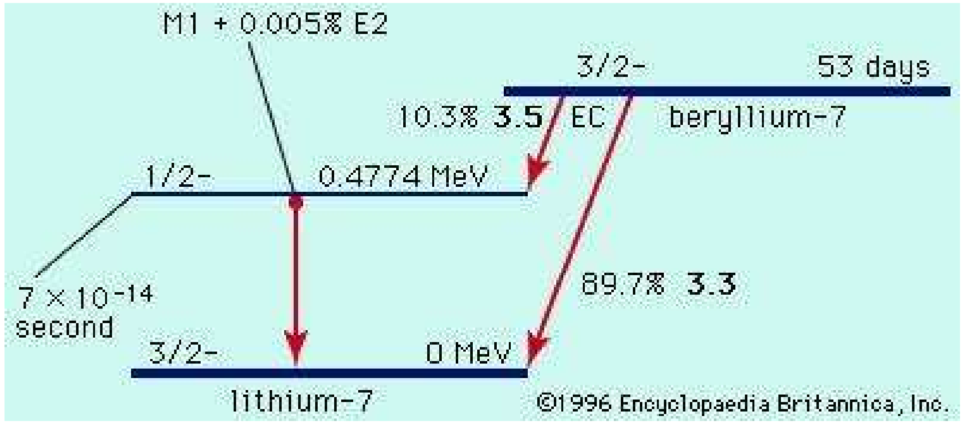


* R.H.Cyburt et al., Journal of Cosmology and Astroparticle Physics 11 (2008) 012

** A.Coc et al., The Astrophysical Journal, 744:158 (2012)

Solution to CLiP?

Approximately 95% of primordial **^{7}Li** is produced from the electron capture decay of **^{7}Be** ($T_{1/2}$=53.2 d).



A higher destruction rate of ^{7}Be can solve or at least partially explain the **CLiP.**

^{7}Be is destroyed via **(n,p)** **(~97%)** and **(n,α)** **(~2.5%)** reactions

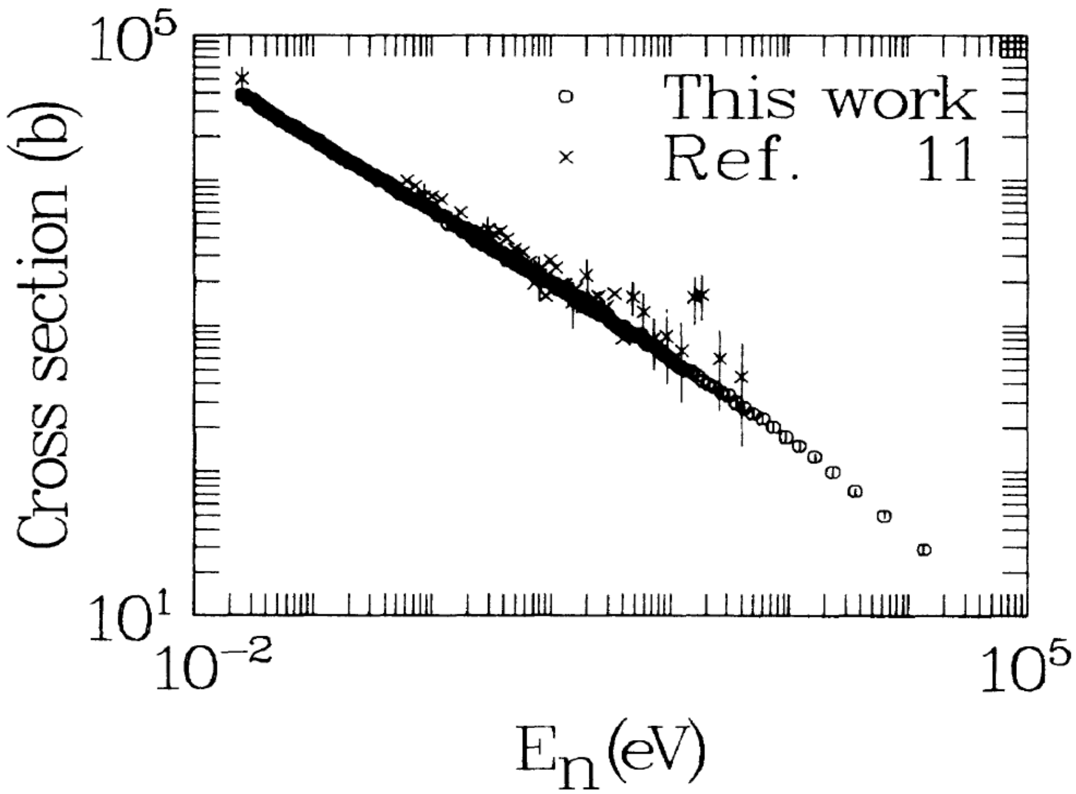
$n + {}^7Be \longrightarrow p + {}^7Li$ Q= 1.644 MeV

$n + {}^7Be \longrightarrow \alpha + \alpha$ Q= 19 MeV

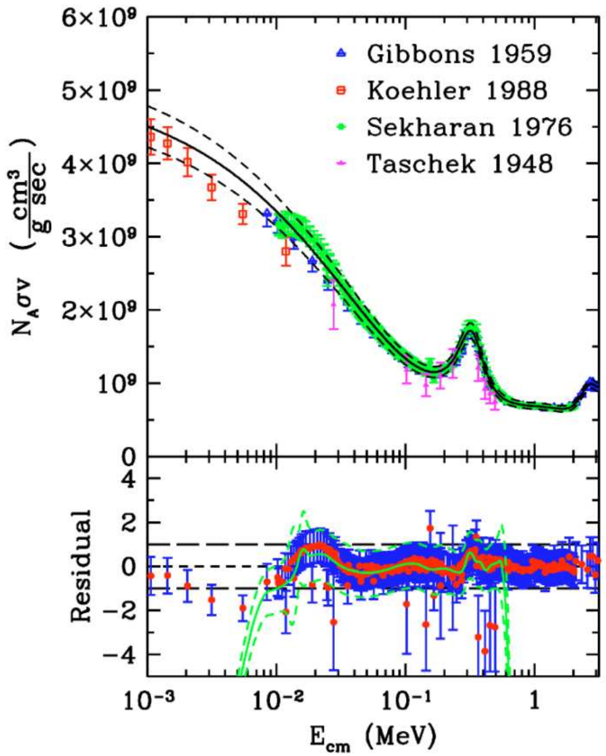
Status of evaluations and experimental data: ^{7}Be(n,p)

Only one direct measurement (Koehler et al., 1988, 0.025 eV - 13.5 keV), covering partially the range of BBN interest **(few keV–few hundreds of keV).**

Direct measurements



Indirect measurements

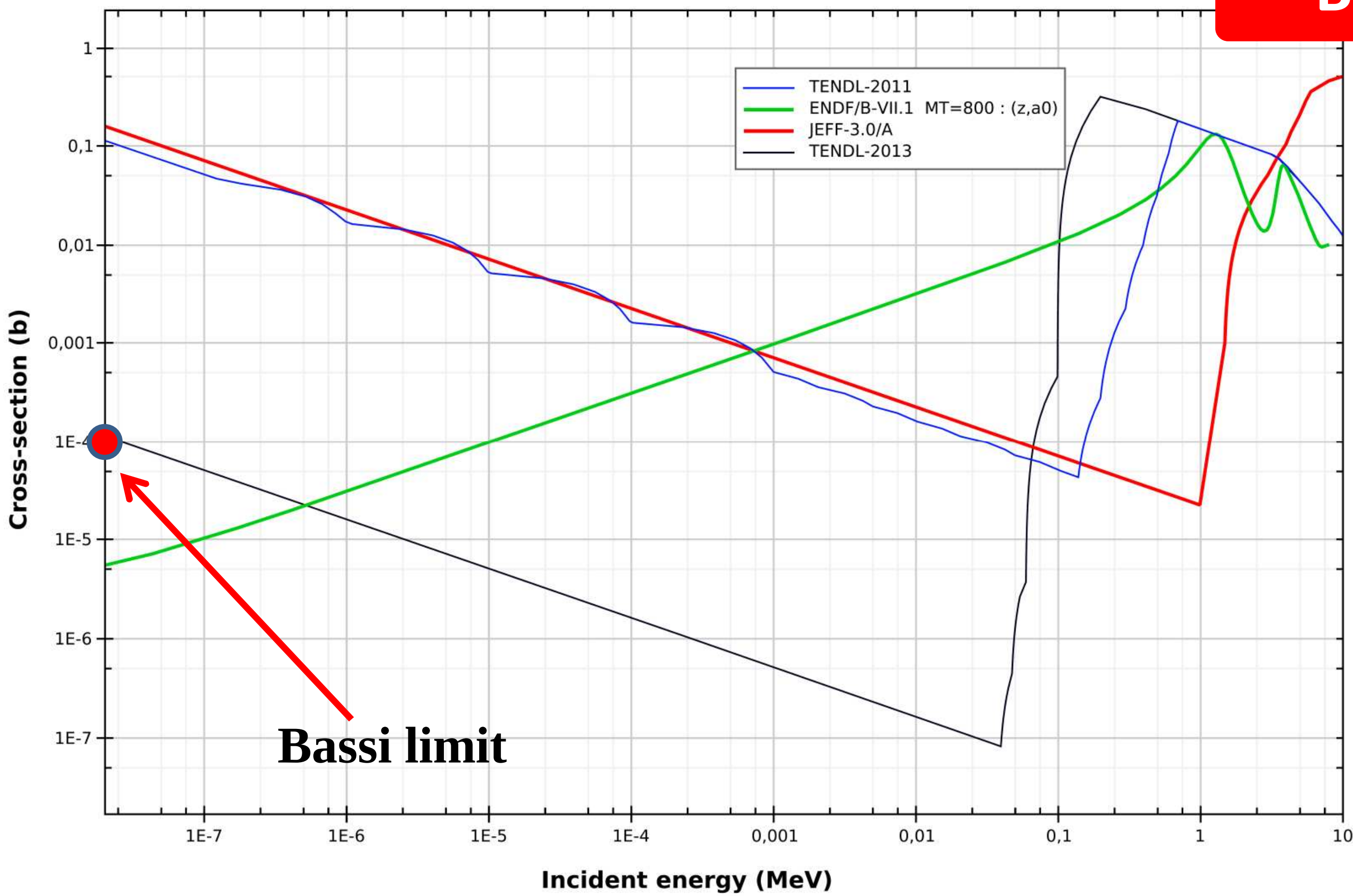


BBN calculations rely on **extrapolation to higher energies** of Koehler data or on **indirect measurements**

Status of evaluations and experimental data

Only one direct measurement (P. Bassi et al., 1963, **@ <u>0.025 eV</u>**) giving an **upper limit** for the cross section at thermal energy **(<0.1 mb)**

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



The (n,p) measurement in EAR2 @n_TOF

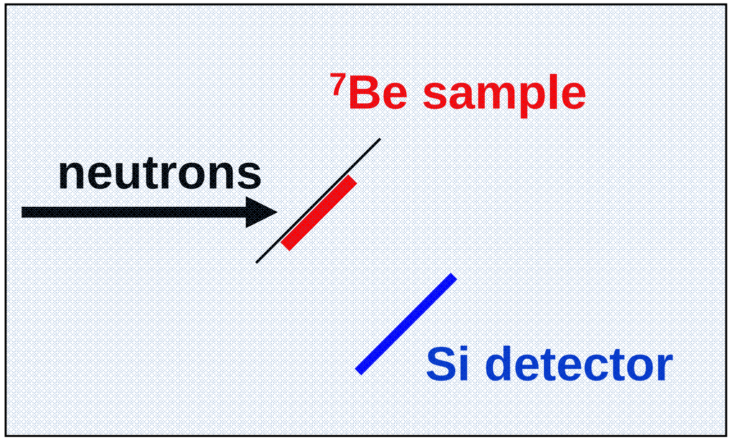
$^{7}Be(n,p)$

Silicon detector (*4x4 cm^2 and 300 μm thickness, or wider area*) **outside of the beam**

Detection of protons (E~ 1 MeV or 1.4 MeV)

↓

Purification of sample needed: ISOLDE



Sample:

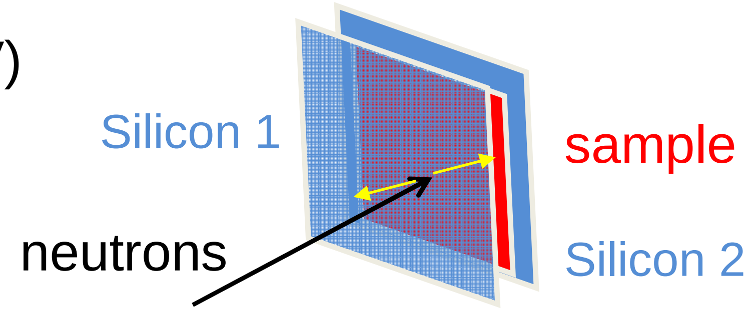
- 100 ng of ^{7}Be (material from water cooling of SINQ spallation source at **PSI**)
- **Offline mass separation required at ISOLDE** ≤1 day (starting from 100 GBq)
- Implantation on backing

The (n,α) measurement in EAR2@n_TOF

Sandwich of silicon detectors (*3x3 cm^2 and 100 or 200 μm thickness*) **directly inserted in the beam.**

^{7}Be(n,α)

Detection of both alpha particles (E~ 9 MeV)



Coincidence technique and high threshold:
Strong rejection of background

Sample:

- 1-10 μg of ^{7}Be from water cooling of SINQ spallation target.
- Activity of 478 keV γ-rays 1 GBq/μg
- Isotopic composition: 1:1 ^{7}Be-^{10}Be 1:5 ^{7}Be-^{9}Be
- Chemical compound: nitrate, chloride or oxide

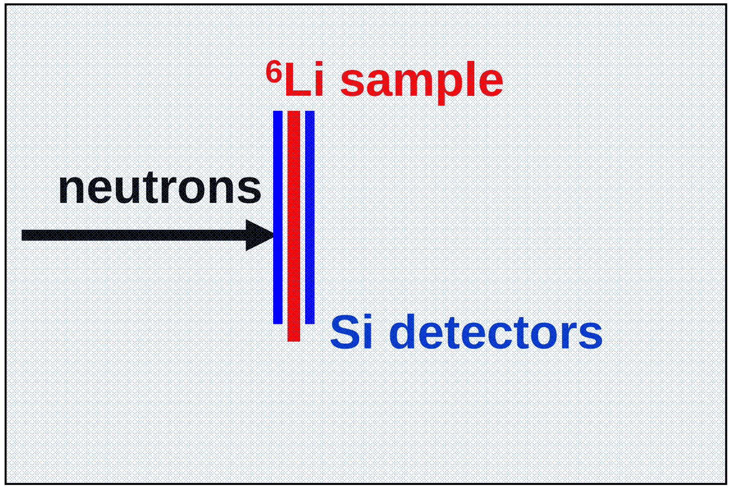
No need for isotopic enrichment (chemical purification is enough)

Test Measurement

We propose to place two silicon detectors (with a Lithium foil) **in** the neutron beam @ **EAR2**.

We ask **1.5x10^{18} protons**

We also plan to perform at **PSI** a test depositing a small fraction of ^{7}Be (<0.1GBq) on the detector



Objective of this proposal

- Silicon detectors directly in the beam **never done @ n_TOF** → background, damage
- Allocate 3 shifts for sample preparation @ **ISOLDE**
- Coordinate with PSI for material extraction and chemical separation

Possibility to run part of the measurement in parallel or during the commissioning.

If successfully, the test will provide a new possibility to measure (n,p) and (n,α) reactions.

Conclusions

• Uncertainties in nuclear data strongly affect the Big Bang Nucleosynthesis calculations for the abundance of ^{7}Li and could probably explain (at least partially) the **C**osmological **Li**thium **P**roblem.

• We plan to measure at **n_TOF EAR2** **for the first time** the ^{7}Be(n,p) and ^{7}Be(n,α) cross sections in the whole range of interest for BBN, with the aim of reducing uncertainties in nuclear data used in calculations, thus setting stronger constraints to BBN theory and on CLiP.

• The needed ^{7}Be is **available at PSI**:

- For the (n,p) measurement, isotopic purity will be done at ISOLDE (100 ng)
  (3 shifts of offline ISOLDE mass separation – no protons requested)
- For the (n,α) measurement, no need for isotope separation (8 μg)

• **1.5x10^{18} protons** requested at n_TOF EAR2 to test effect of direct neutrons on silicon detectors

- check background induced on Si-detectors
- check degradation related to n and γ dose

• **Following to the results of the test, an addendum with the protons request for the (n,p) and (n,α) measurements will be submitted.**

Thanks for your attention

Back-up slides

^{7}Be destruction

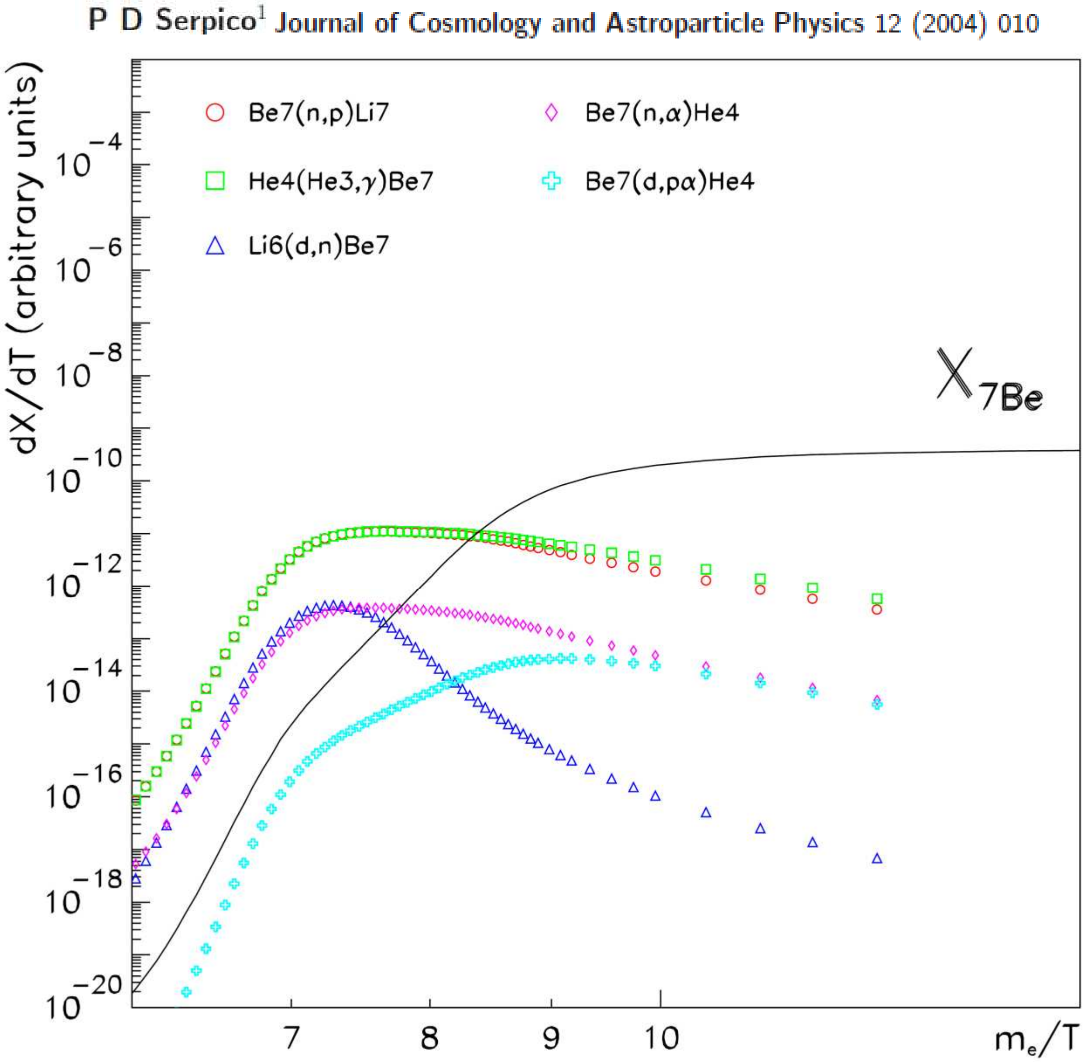


Figure B.7. Leading processes for production and destruction of ^{7}Be.

Background sources

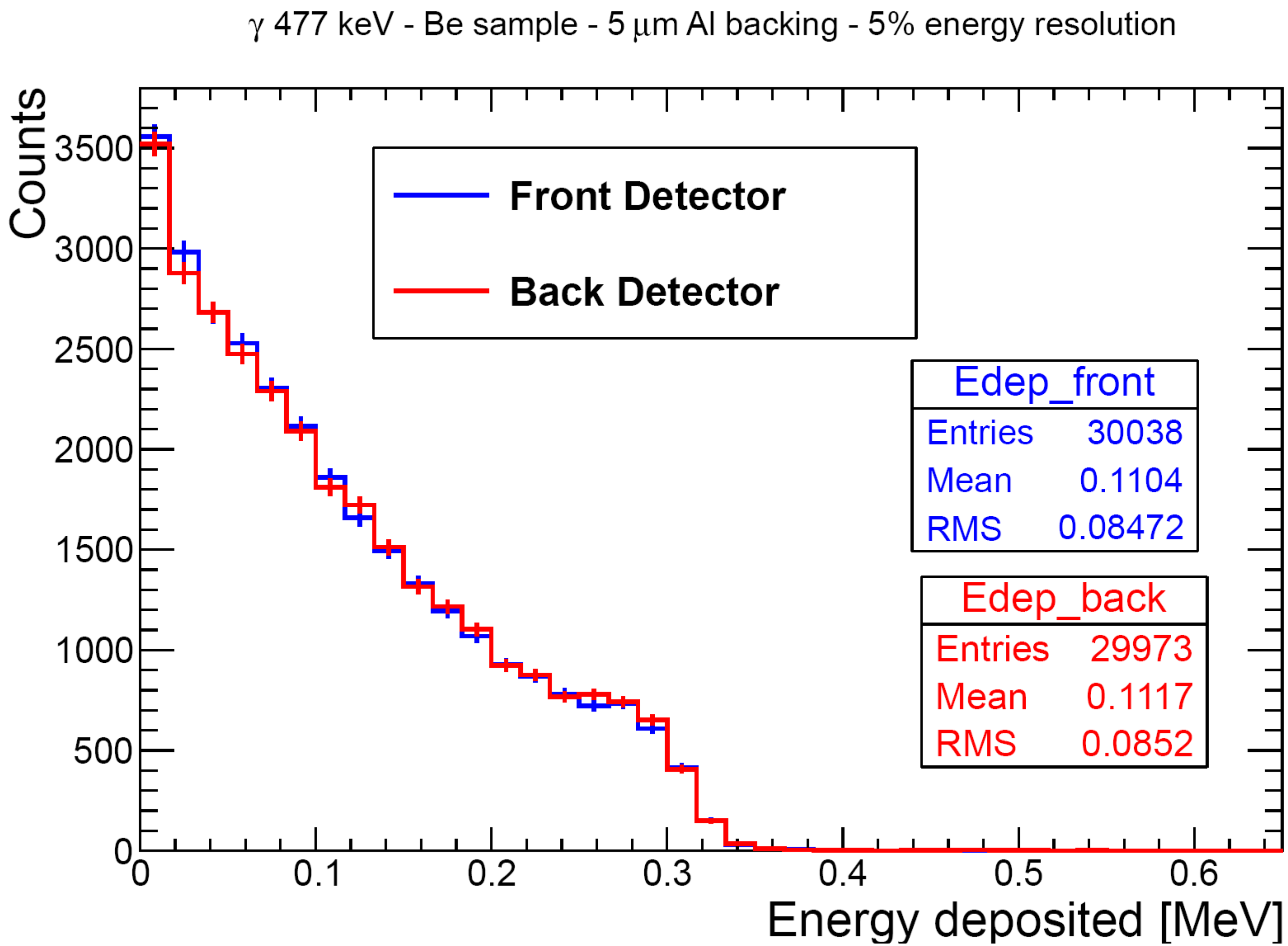
$^{7}Be(n,\alpha)$

- ^{28}Si
- ^{27}Al
- ^{16}O
- H
- C
- **^{9}Be**
- **^{10}Be**

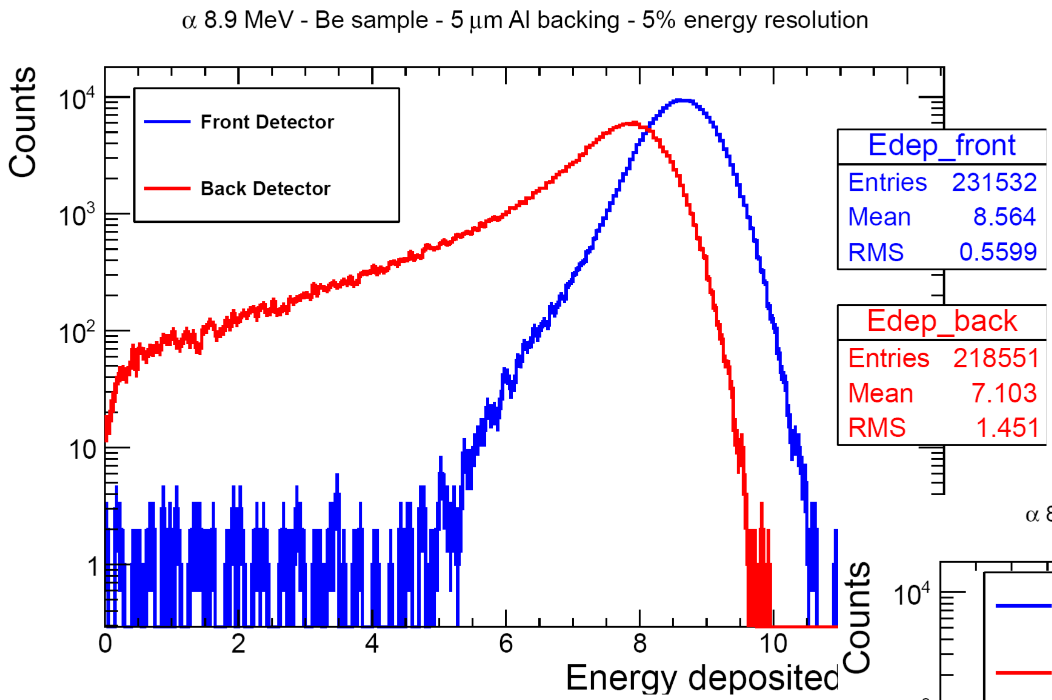
$^{7}Be(n,p)$

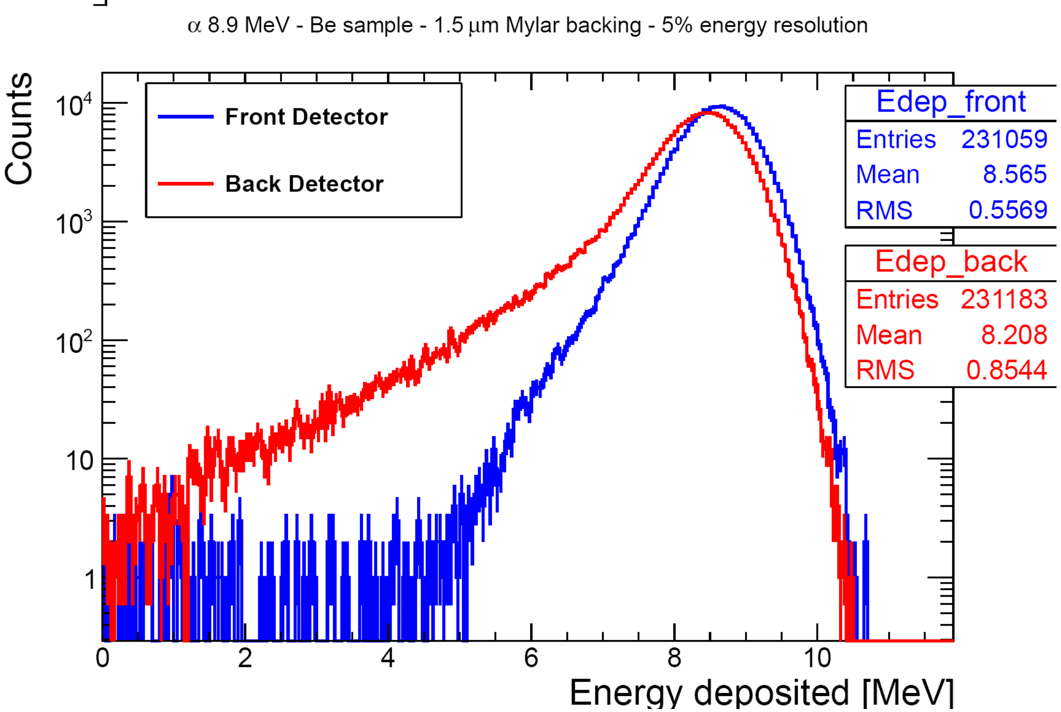
- ^{28}Si
- ^{27}Al
- ^{16}O
- C
- H

Energy deposition of 477 keV gamma

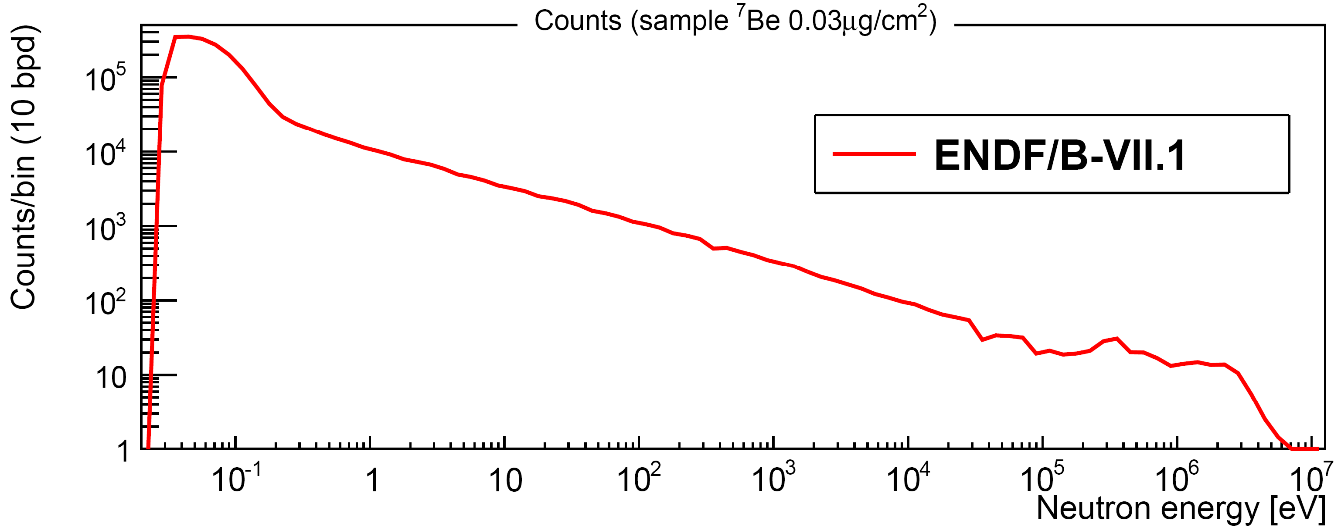


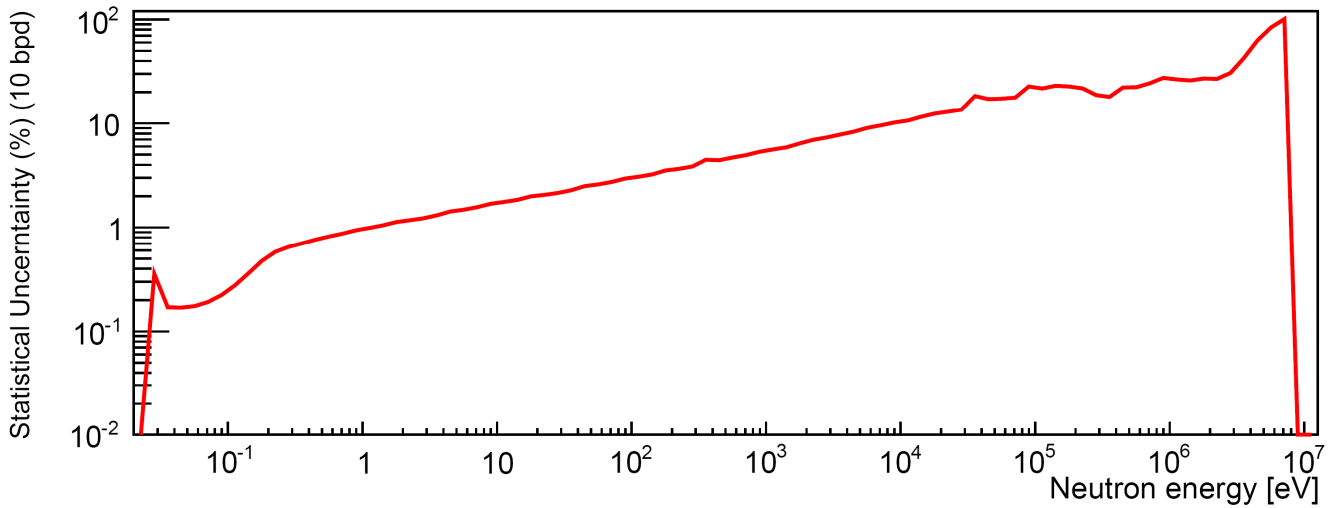
Energy loss of alpha from n(^{7}Be,α)α





Expected counts

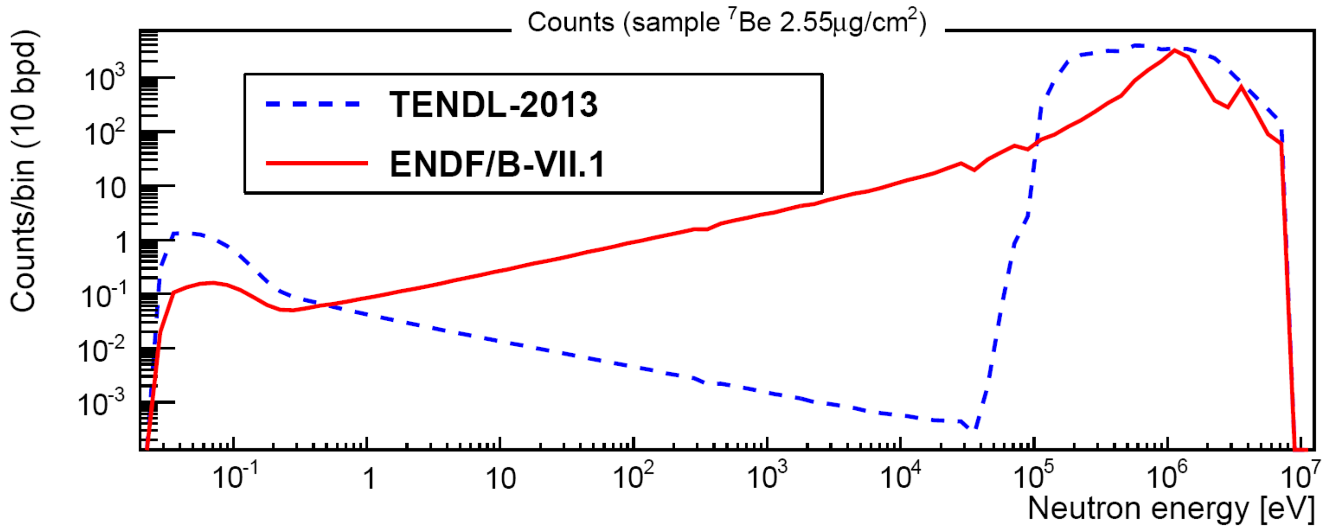


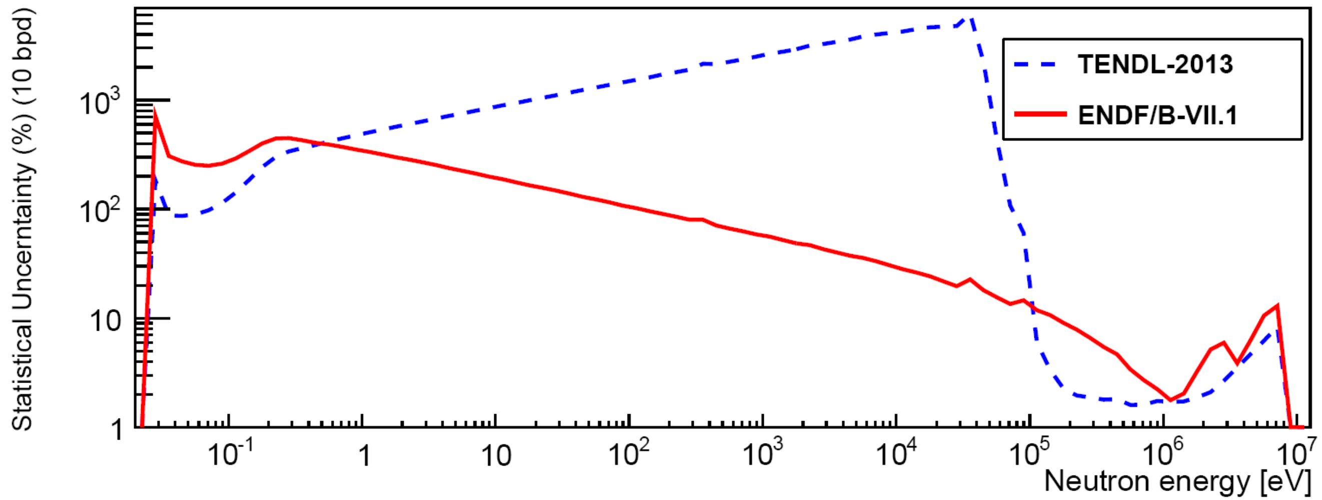


^{7}Be(n,p)

- 90 ng of ^{7}Be on 2 cm diameter circular area
- Efficiency 20%
- Flux= 10x Flux@EAR1
- 1.5X10^{18} protons

Expected counts





^{7}Be(n,α)

- 8 μg of ^{7}Be on 2 cm diameter circular area
- Efficiency 95%
- Flux= 10x Flux@EAR1
- 5X10^{18} protons