Cosmological Lithium problem: measurement of ^{7}Be(n,α) and ^{7}Be(n,p) cross-sections at the n_TOF facility at CERN

M. Barbagallo[1,2], on behalf of the n_TOF Collaboration[2]

1-Istituto Nazionale di Fisica Nucleare, sez. di Bari

2-CERN

Nuclear Physics in Astrophysics VIII

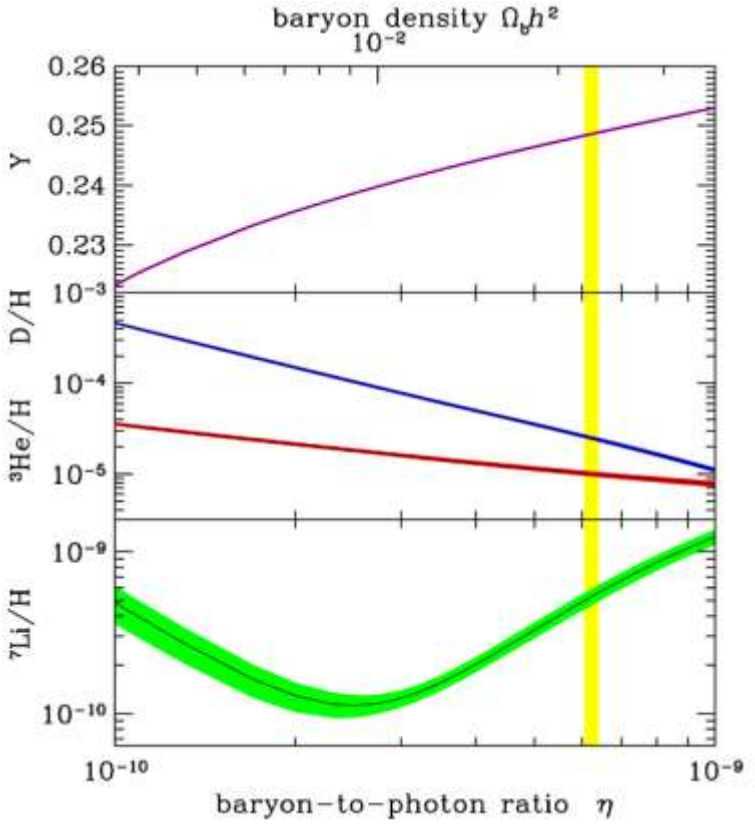
Laboratori Nazionali del Sud, Catania, June 18-23 2017

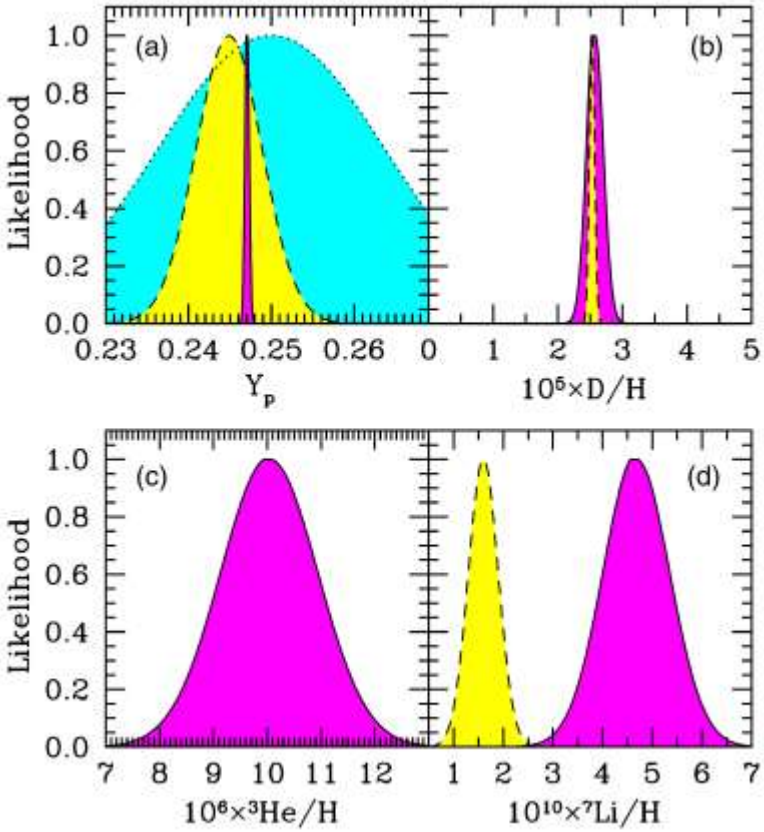
Summary

- The Cosmological Lithium Problem
- The n_TOF Facility
- The ^{7}Be(n,α) cross section measurement and its implications
- The ^{7}Be(n,p) cross section measurement
- Conclusions

Cosmological Lithium Problem

BBN successfully predicts the abundancies of light elements, i.e. D and ^{4}He, but…



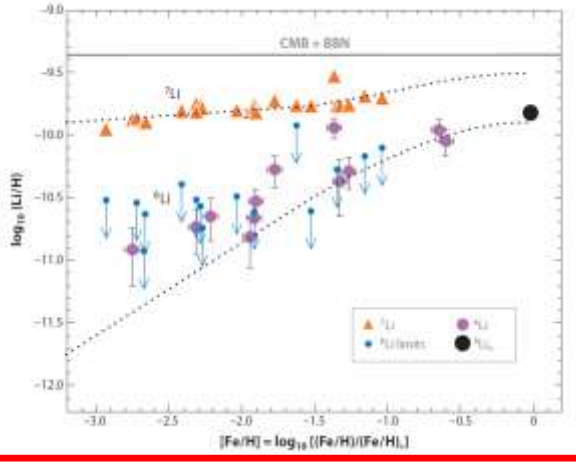


Serious discrepancy between the predicted abundance of **^{7}Li** and the value inferred by measurements (Spite et al.) ⟹ **Cosmological Lithium problem (CLiP)**

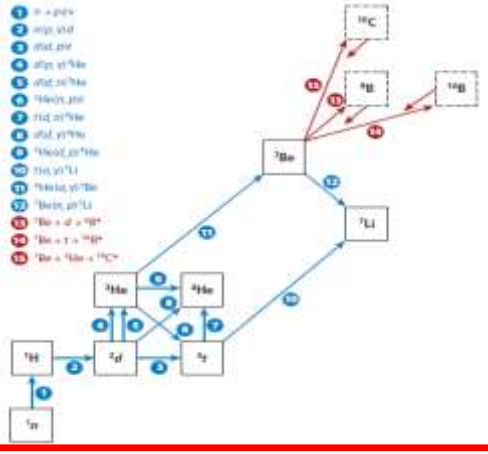
Solutions to CLiP

(At least) Three classes of solutions for this longstanding problem:

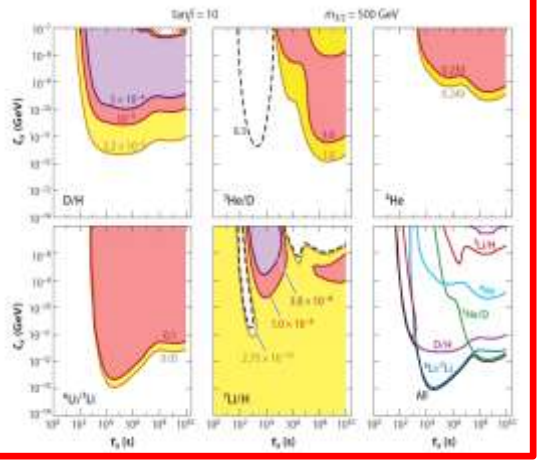
Astrophysical



Nuclear Physics



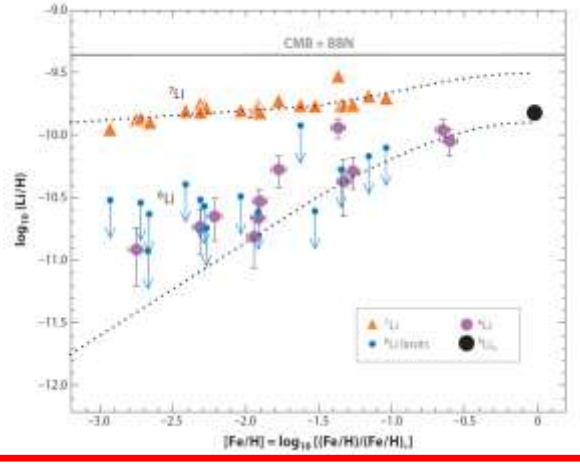
Non Standard Physics



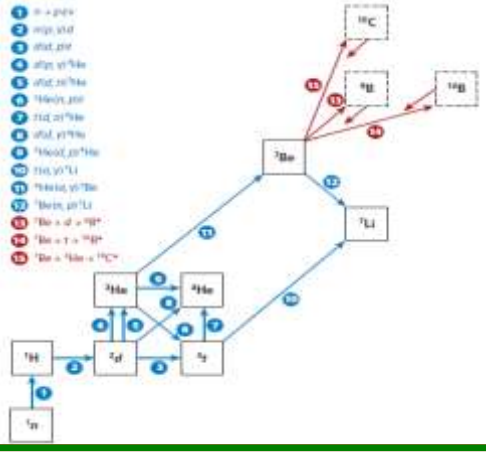
Solutions to CLiP

(At least) Three classes of solutions for this longstanding problem:

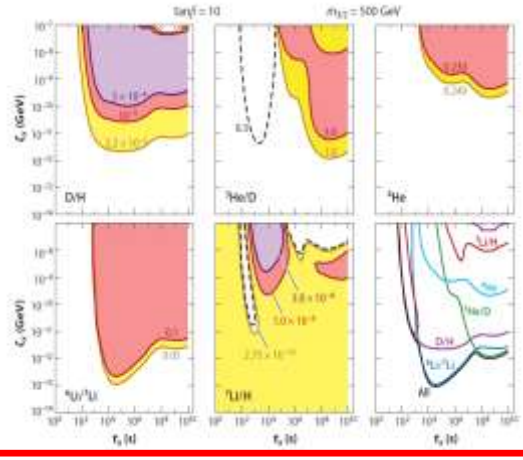
Astrophysical



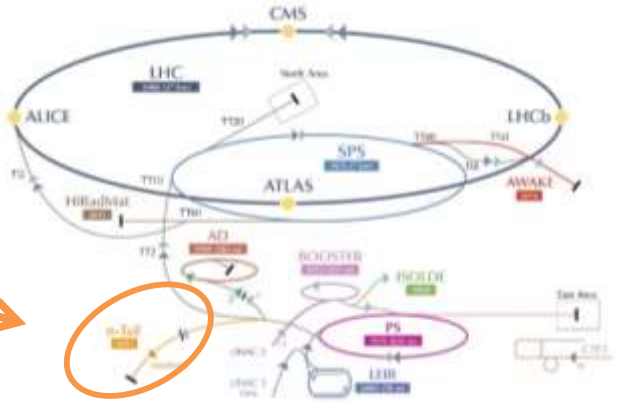
Nuclear Physics



Non Standard Physics



Neutron Time Of Flight facility: **n_TOF**



Cosmological Lithium Problem and ^{7}Be

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

Nuclear Physics solution to CLiP

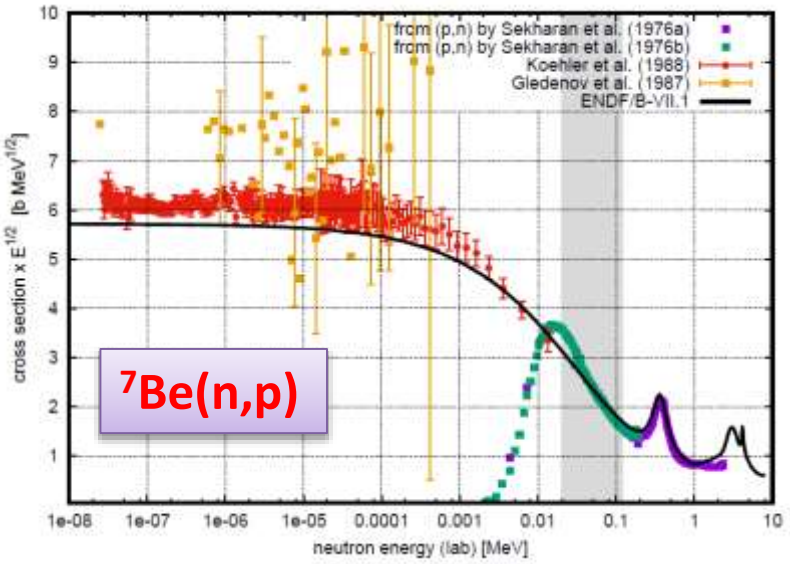
- ^{7}Be decay rate in plasma(?)
- ^{7}Be production channels have been widely investigated and they are known with good accuracy.
- ^{7}Be is destroyed via **(n,p)** and (p,x), (d,x), (^{3}He,x), … reactions. Small contribution of the **(n,α)** reactions according to **estimated** cross section.

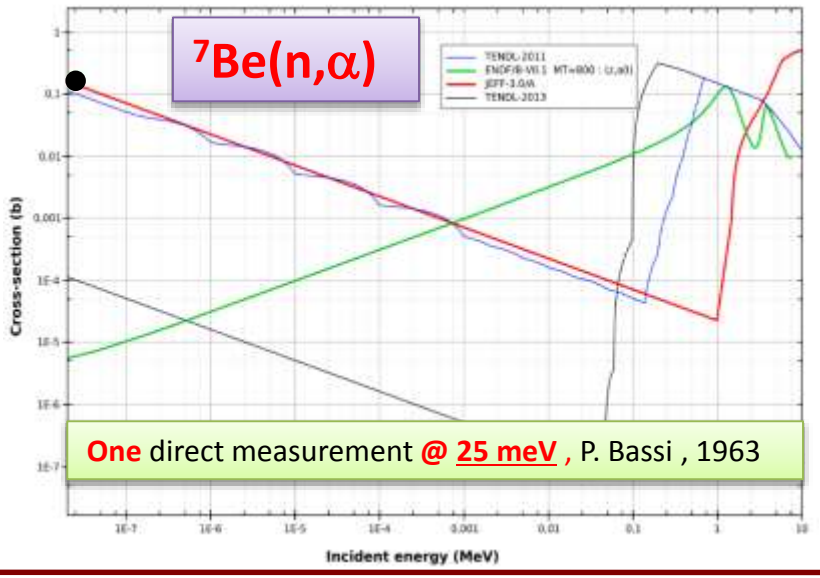
Cosmological Lithium Problem and ^{7}Be

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

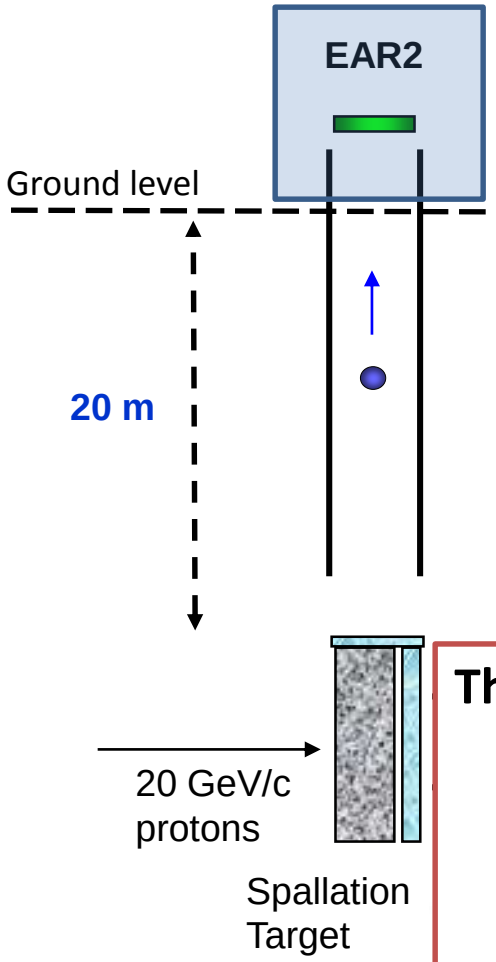
Nuclear Physics solution to CLiP

- ^{7}Be decay rate in plasma(?)
- ^{7}Be production channels have been widely investigated and they are known with good accuracy.
- ^{7}Be is destroyed via **(n,p)** and (p,x), (d,x), (^{3}He,x), … reactions. Small contribution of the **(n,α)** reactions according to **estimated** cross section.





n_TOF program on CLiP



Two different measurements at n_TOF-EAR2

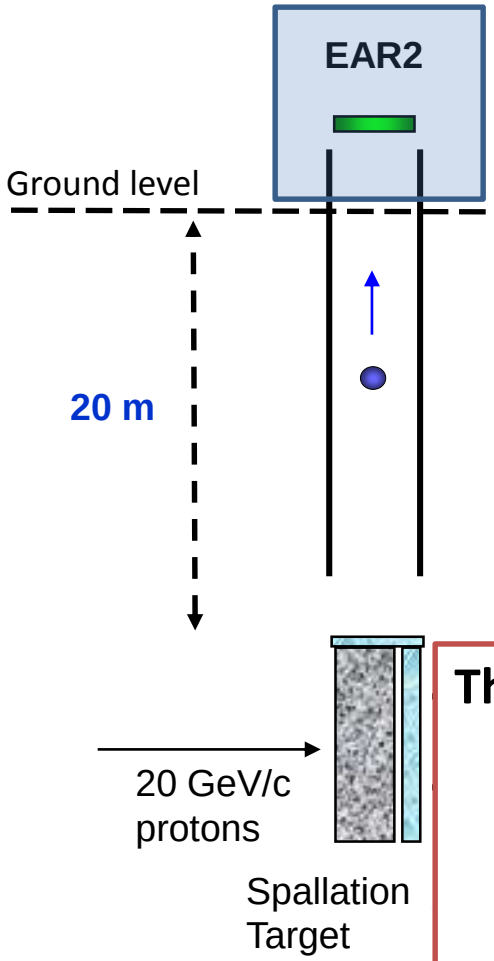
i) $n+^{7}Be \rightarrow \alpha+\alpha$ — 2015 measurement campaign

ii) $n+^{7}Be \rightarrow p+^{7}Li$ — 2016 measurement ampaign

The much higher flux in EAR2 allows to:

- measure samples of **very small mass (<<1 mg)**
- measure **short-lived radioisotopes** (i.e. **53.2 d!**)
- collect data on a much **shorter time**
- **measure (n,charged particle)** reactions with **thin samples**

n_TOF program on CLiP



Two different measurements at n_TOF-EAR2

i) $n+^{7}Be \rightarrow \alpha+\alpha$ — 2015 measurement campaign

ii) $n+^{7}Be \rightarrow p+^{7}Li$ — 2016 measurement ampaign

13 GBq/μg !!!
(γ 475 keV,10%)

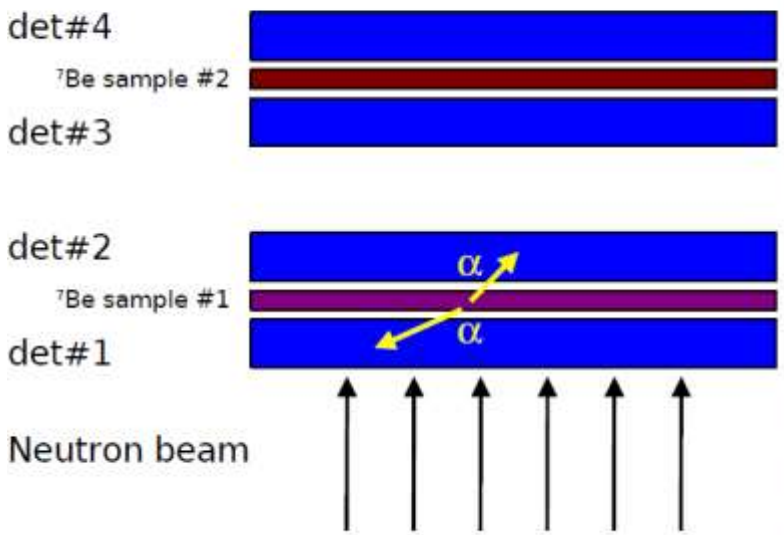
The much higher flux in EAR2 allows to:

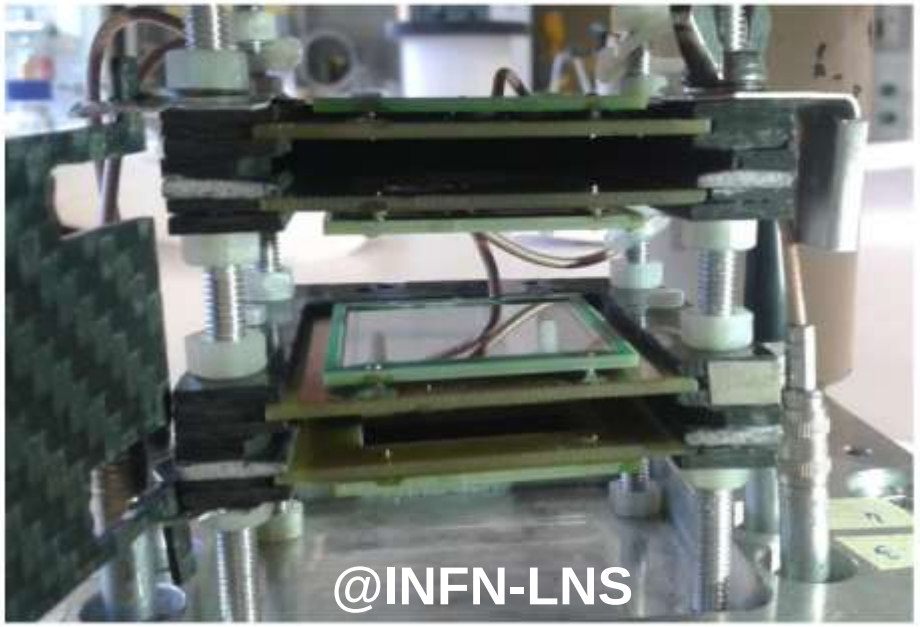
- measure samples of **very small mass (<<1 mg)**
- measure **short-lived radioisotopes** (i.e. **53.2 d!**)
- collect data on a much **shorter time**
- **measure (n,charged particle)** reactions with **thin samples**

$^{7}Be(n,\gamma\alpha)^{4}He$ measurement: setup

$n + {}^{7}Be \dashrightarrow {}^{8}Be^{*} \dashrightarrow \alpha + \alpha\ (+\gamma)$ Q ~19 MeV

- Silicon detectors directly inserted in the beam (3x3 cm^2 active area, 140 μm thickness)
- Two different samples, 40 GBq total activity





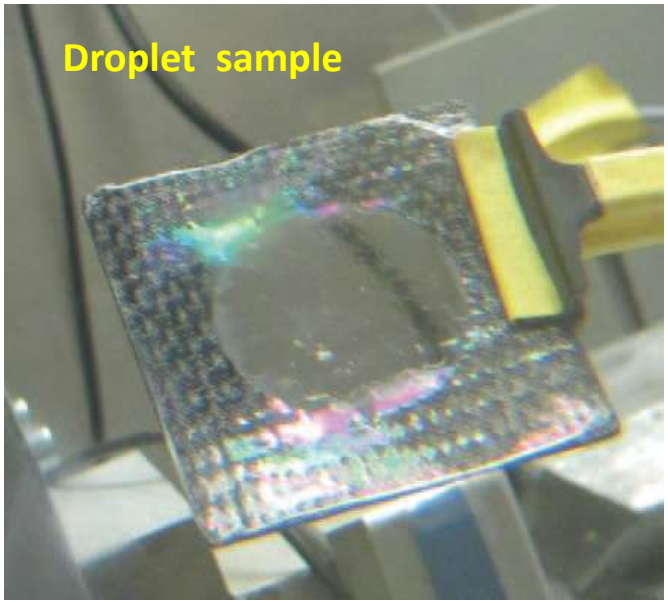
L. Cosentino et al. (n_TOF Coll.), NIM A 830 (2016) 197-205

Such a setup offered, among other features, redundancy, allowing to reduce systematic uncertainties.

^{7}Be(n,γα)^{4}He measurement: setup

Both ^{7}Be samples were prepared at **PSI**, starting from a 200 GBq solution extracted from the spallation target of SINQ source, as $Be(NO_3)_2$ solution.

Before being deposited/evaporated the solution was chemically purified (^{7}Li).



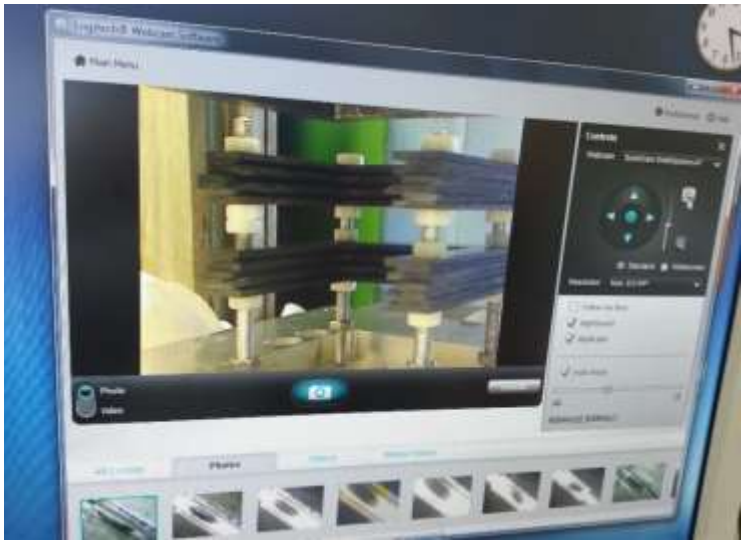
0.6 μm polyethylene stretched foil

5 μm aluminium foil

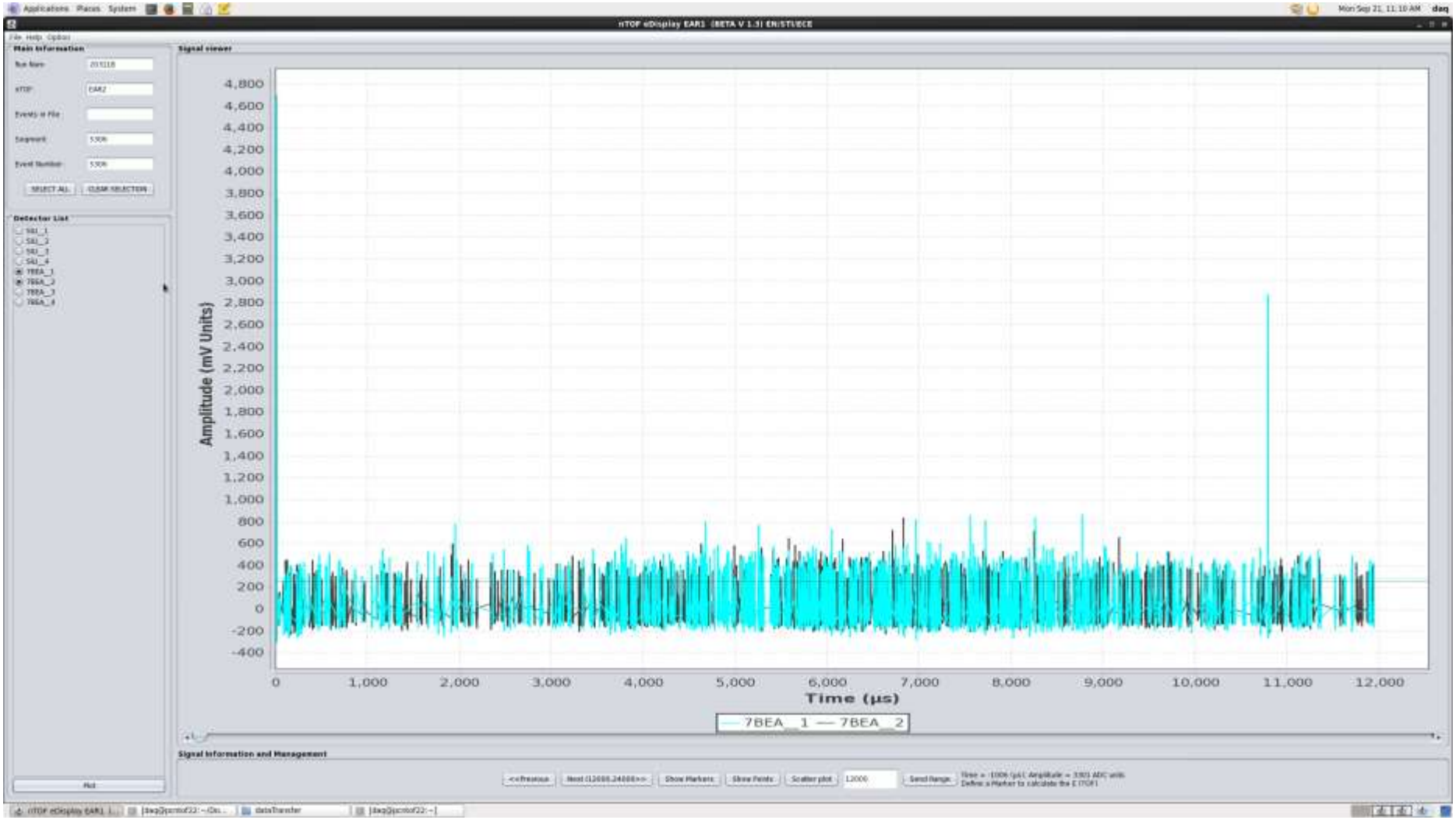
The samples were characterized in terms of thickness and activity.

E. Maugeri et al. (n_TOF Coll.), Journ. of Instr., 12, P02016, (2017)

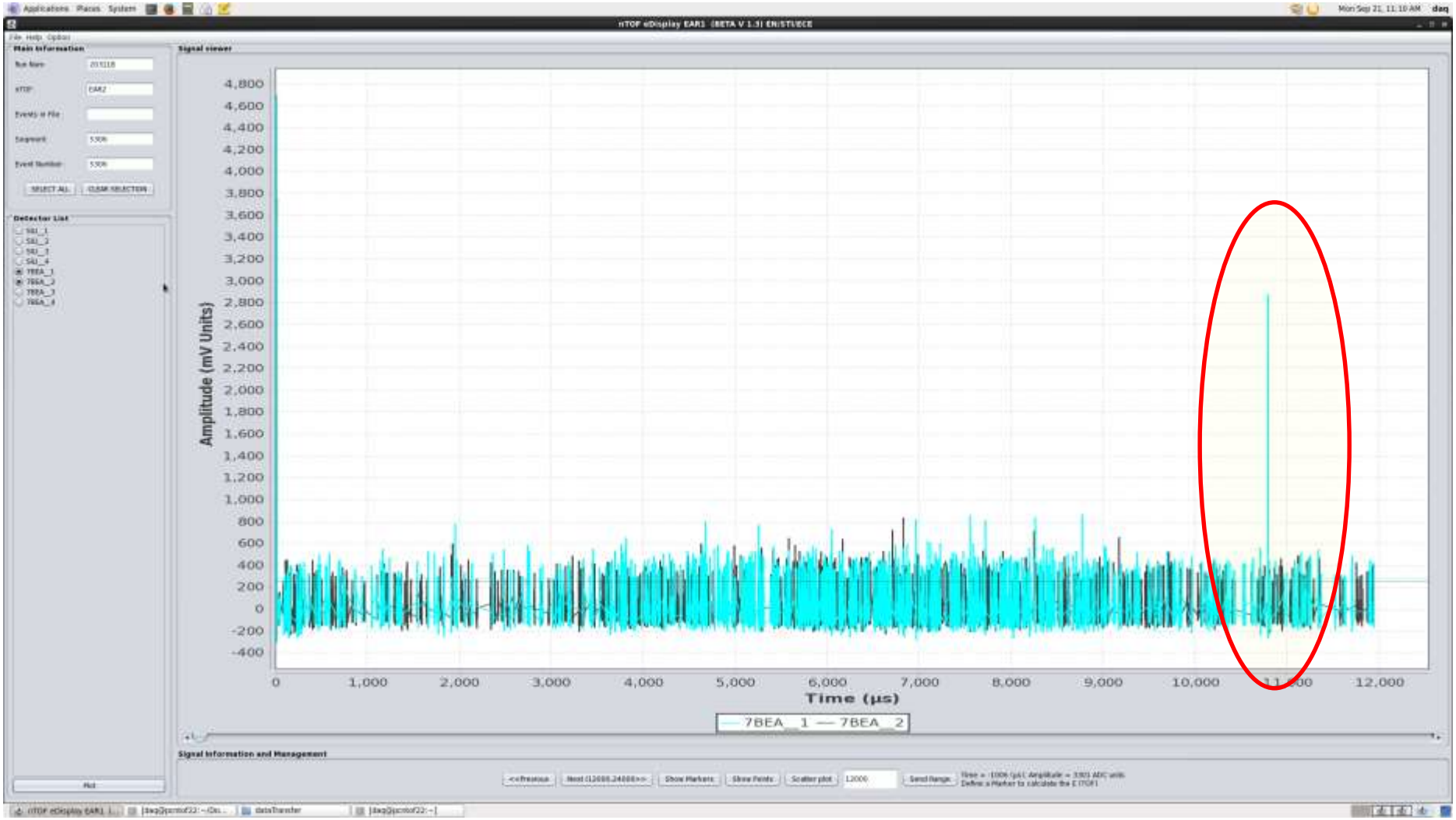
^{7}Be(n,γα)^{4}He measurement: the making of



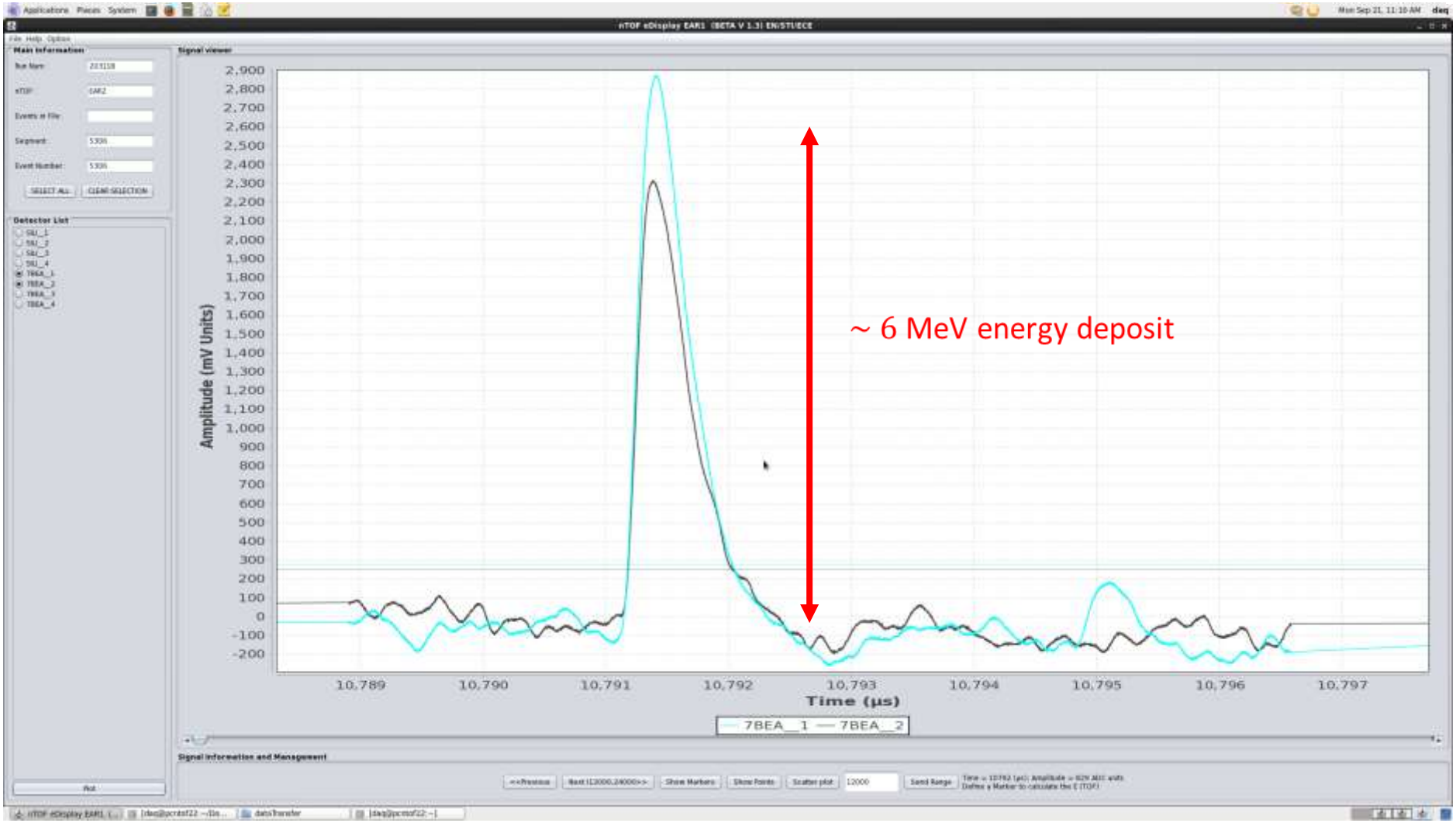
^{7}Be(n,γα)^{4}He measurement: first signal



^{7}Be(n,γα)^{4}He measurement: first signal

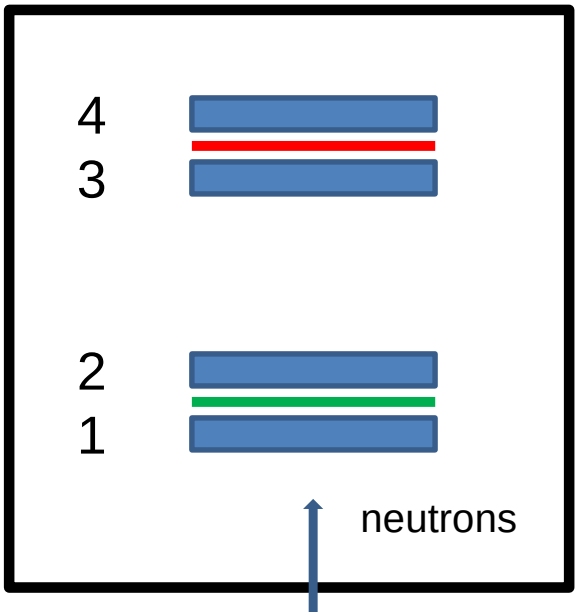


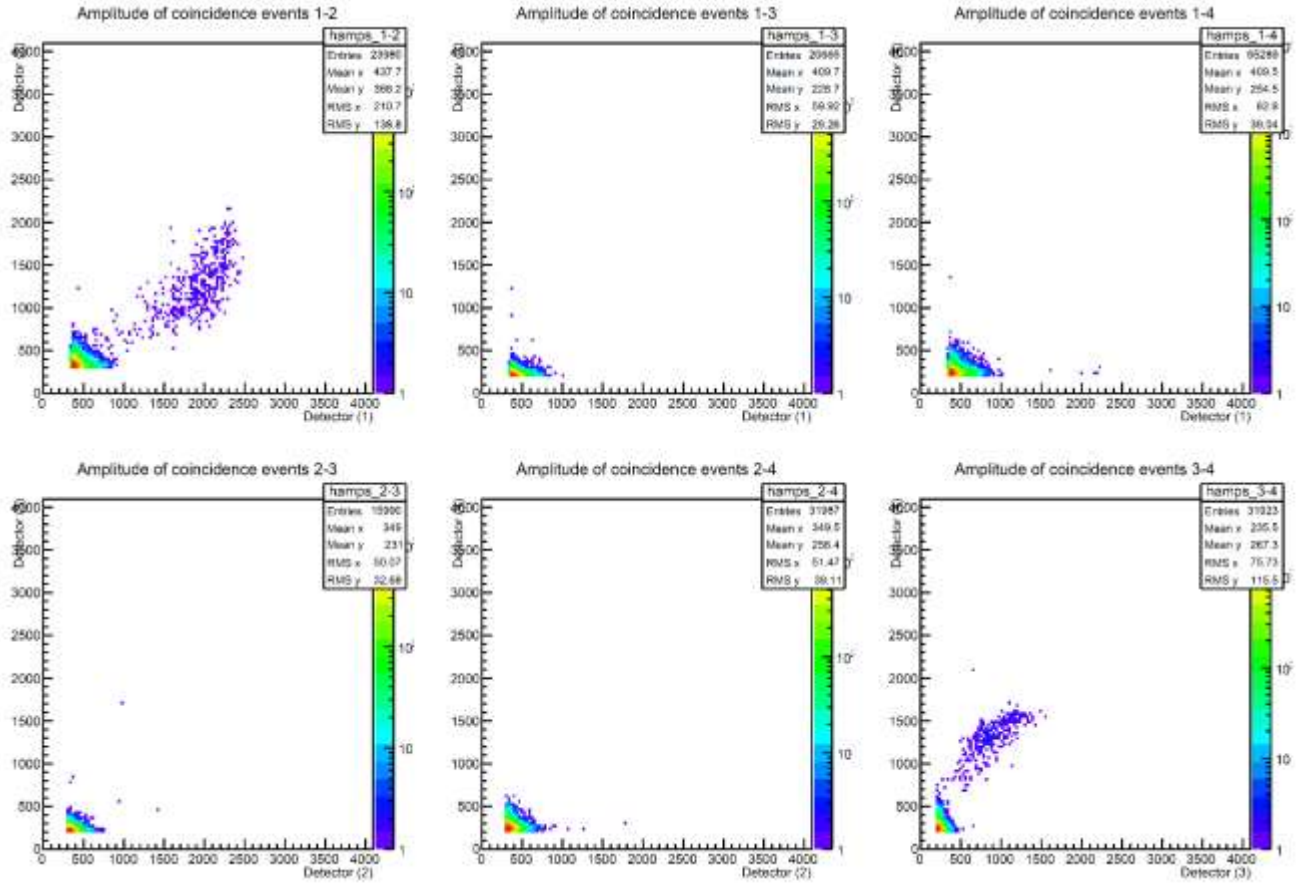
^{7}Be(n,γα)^{4}He measurement: first signal



^{7}Be(n,γα) cross-section measurement

Two different sandwiches of silicon detectors.

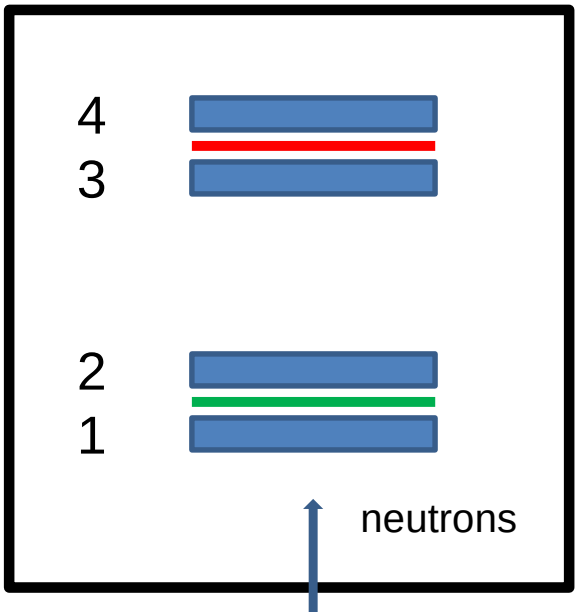


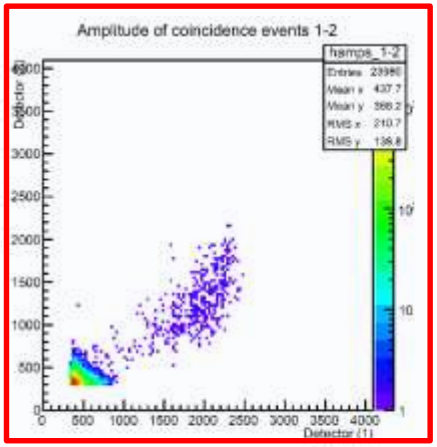


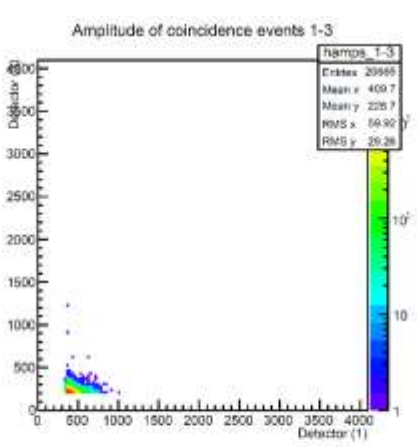
Possible to evaluate random coincidences comparing uncorrelated couples of detectors.

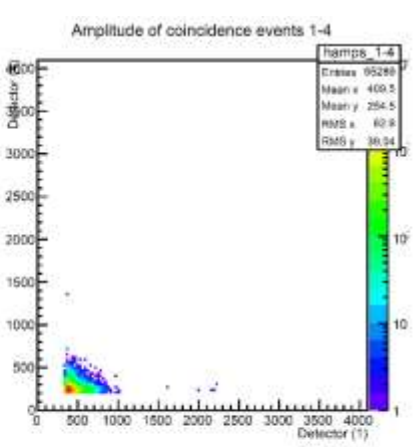
^{7}Be(n,γα) cross-section measurement

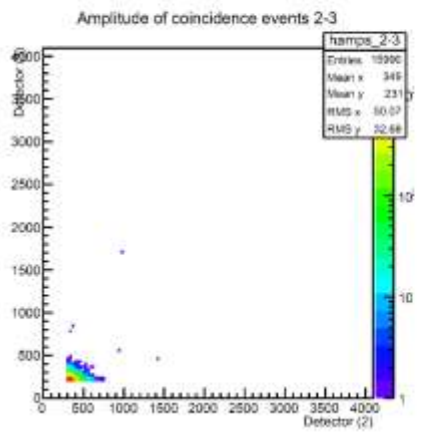
Two different sandwiches of silicon detectors.

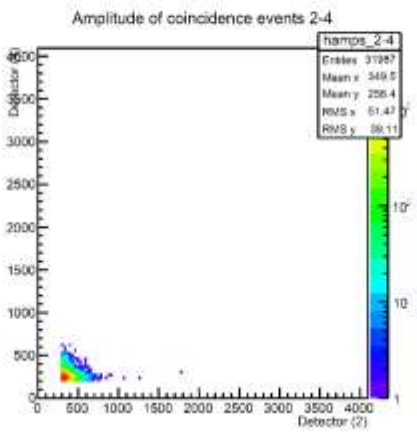


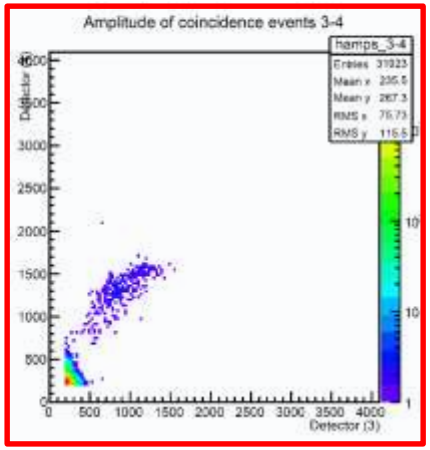












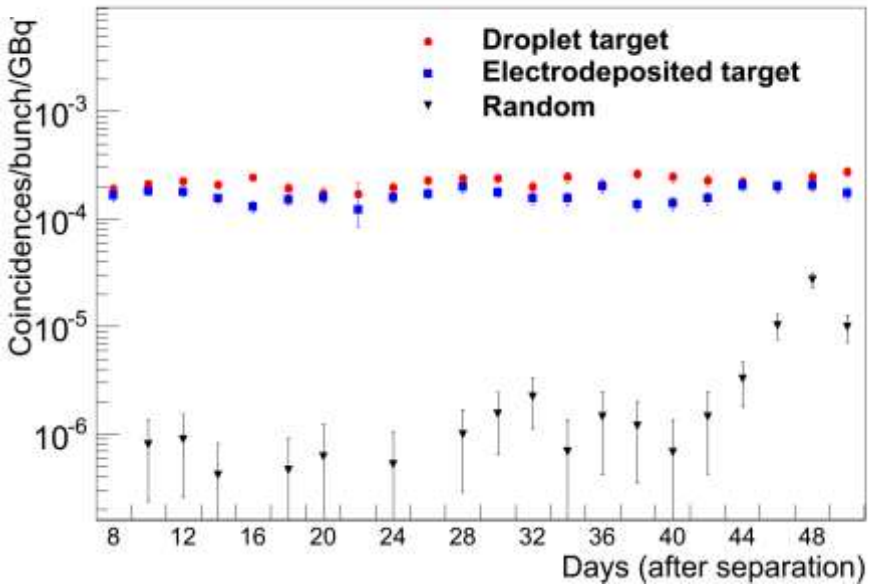
Possible to evaluate random coincidences comparing uncorrelated couples of detectors.

^{7}Be(n,γα)^{4}He measurement: background rejection

Strong rejection of background: coincidence signals, low duty cycle beam, Time-of-Flight.

- Protons from ^{7}Be(n,p) reactions
- γ from ^{7}Be decay
- $n + {}^{7}Li \longrightarrow {}^{8}Li \xrightarrow{\beta\text{-decay}} {}^{8}Be^{*}$ (800 ms) → α+α
- ^{9}Be(n,2n), ^{7}Li(p,γ), ^{7}Be(p,γ)

E_{dep}> 2 MeV



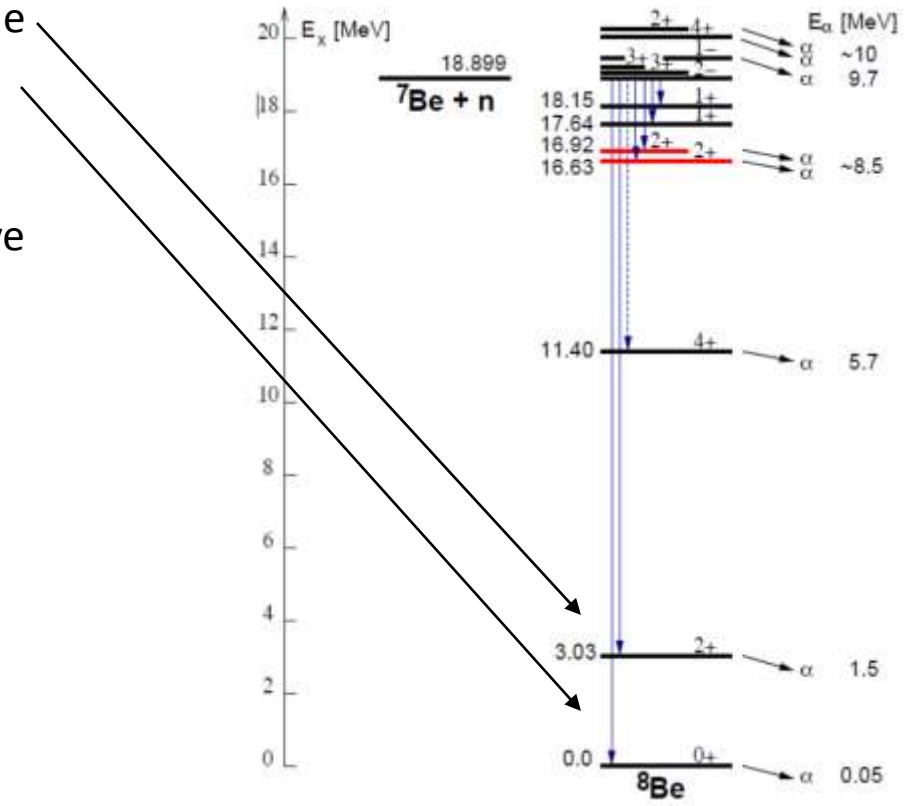
^{7}Be(n,γα)^{4}He measurement: background rejection

Strong rejection of background: coincidence signals, low duty cycle beam, Time-of-Flight.

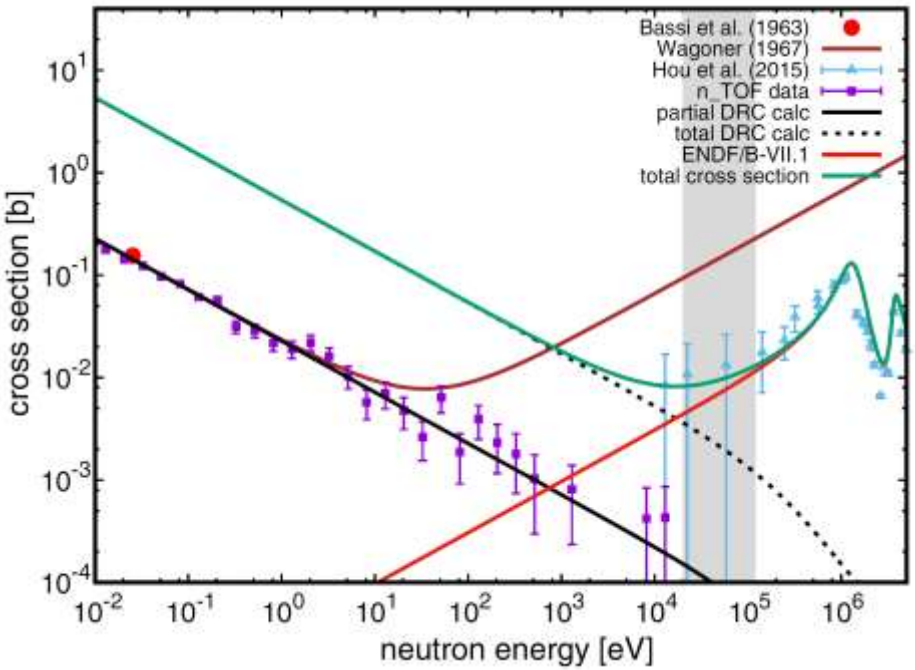
E_{dep}> 2 MeV

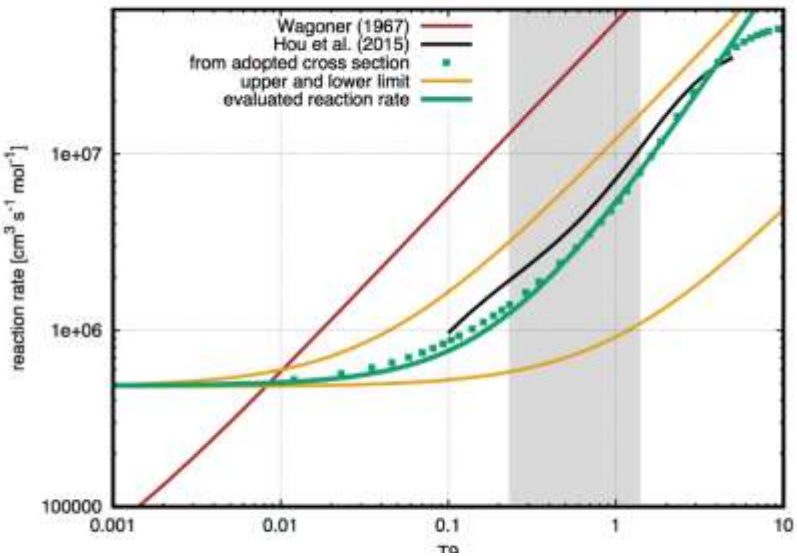
Two low energy states of ^{8}Be not accessible experimentally.

Missing states fractional contributions have been calculated.



$^{7}Be(n,\alpha)^{4}He$ n_TOF results and CLiP



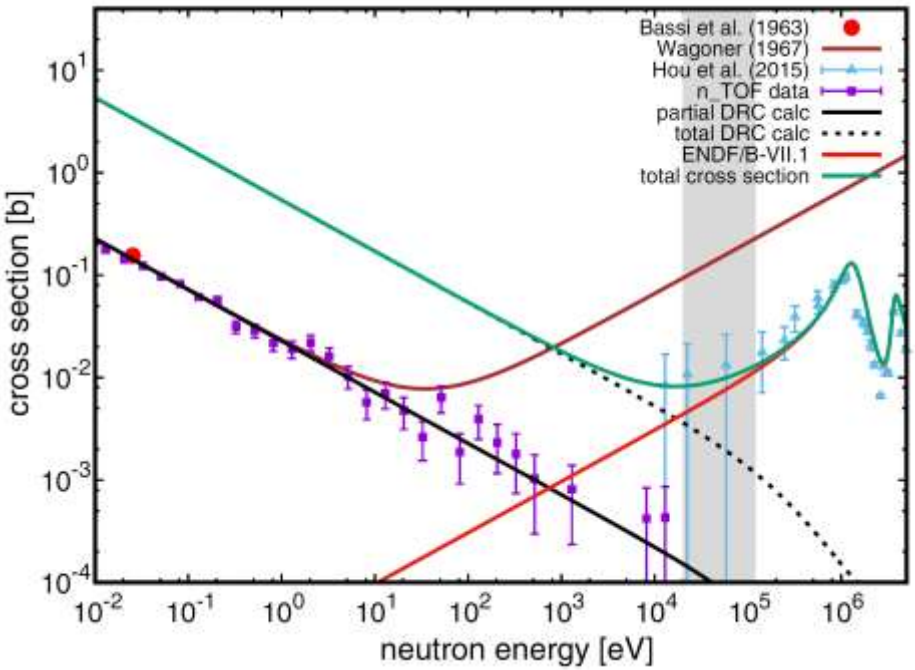


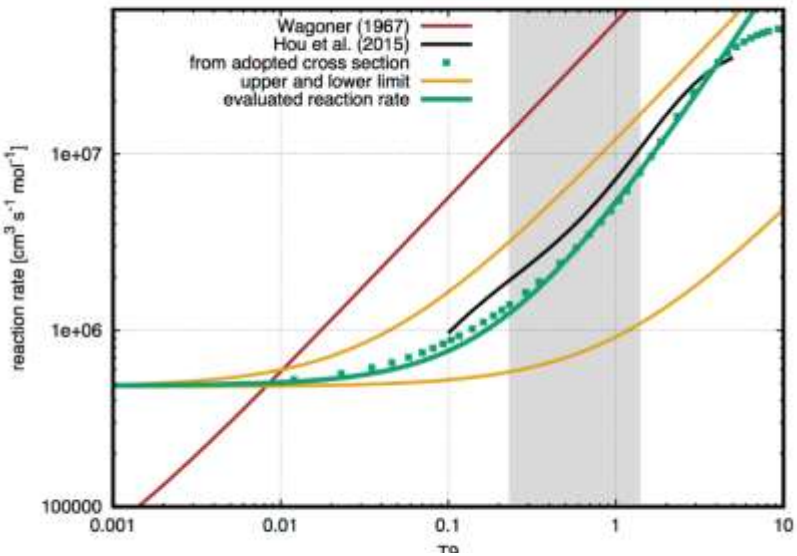
$$N_A\langle\sigma v\rangle = 4.81 \times 10^5 + 1.84 \times 10^6 T_9 + 3.03 \times 10^6 T_9^{3/2}$$

M. Barbagallo et al. (n_TOF Coll.), Phys. Rev. Lett. 117, 152701, 2016

- http://home.cern/about/updates/2016/10/ntof-plays-hide-and-seek-cosmological-lithium
- http://home.infn.it/it/comunicazione/news/1999-il-mistero-nascosto-nei-primi-tre-minuti-di-vita-dell-universo

^{7}Be(n,α)^{4}He n_TOF results and CLiP





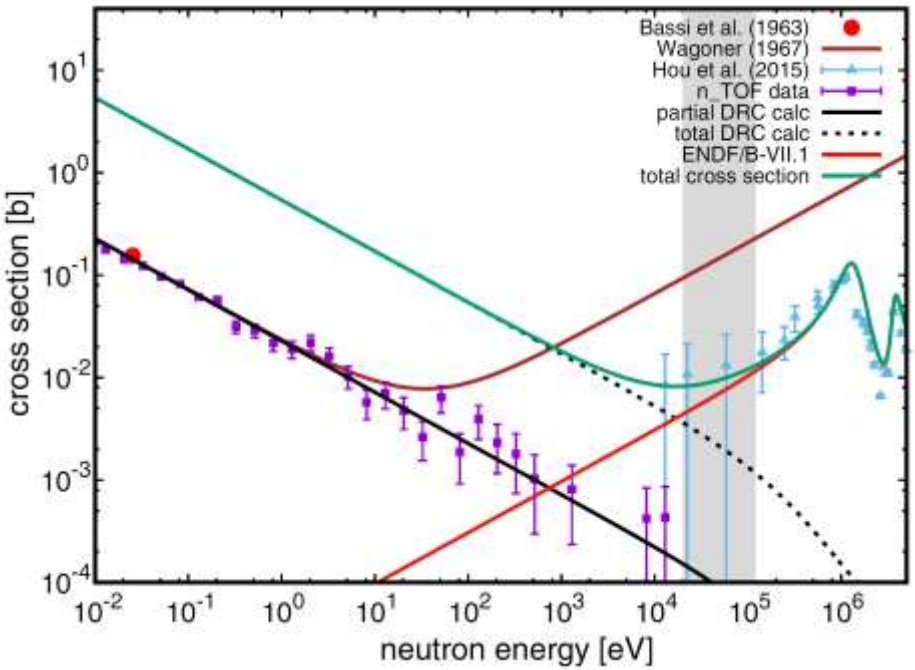
$$N_A\langle\sigma v\rangle = 4.81 \times 10^5 + 1.84 \times 10^6 T_9 + 3.03 \times 10^6 T_9^{3/2}$$

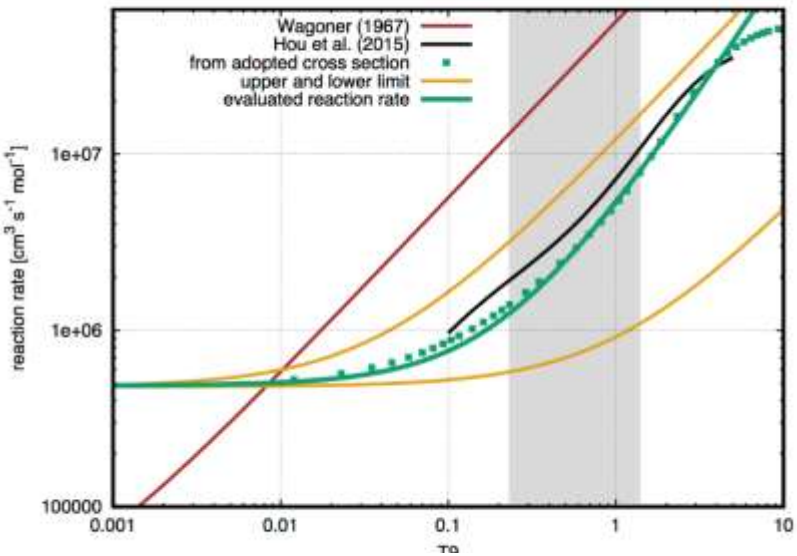
M. Barbagallo et al. (n_TOF Coll.), Phys. Rev. Lett. 117, 152701, 2016

- http://home.cern/about/updates/2016/10/ntof-plays-hide-and-seek-cosmological-lithium
- http://home.infn.it/it/comunicazione/news/1999-il-mistero-nascosto-nei-primi-tre-minuti-di-vita-dell-universo

As for (n,α) measurement, the Cosmological Lithium Problem gets worse!

^{7}Be(n,α)^{4}He n_TOF results and CLiP





$$N_A\langle\sigma v\rangle = 4.81 \times 10^5 + 1.84 \times 10^6 T_9 + 3.03 \times 10^6 T_9^{3/2}$$

M. Barbagallo et al. (n_TOF Coll.), Phys. Rev. Lett. 117, 152701, 2016

- http://home.cern/about/updates/2016/10/ntof-plays-hide-and-seek-cosmological-lithium
- http://home.infn.it/it/comunicazione/news/1999-il-mistero-nascosto-nei-primi-tre-minuti-di-vita-dell-universo

As for (n,α) measurement, the Cosmological Lithium Problem gets worse!

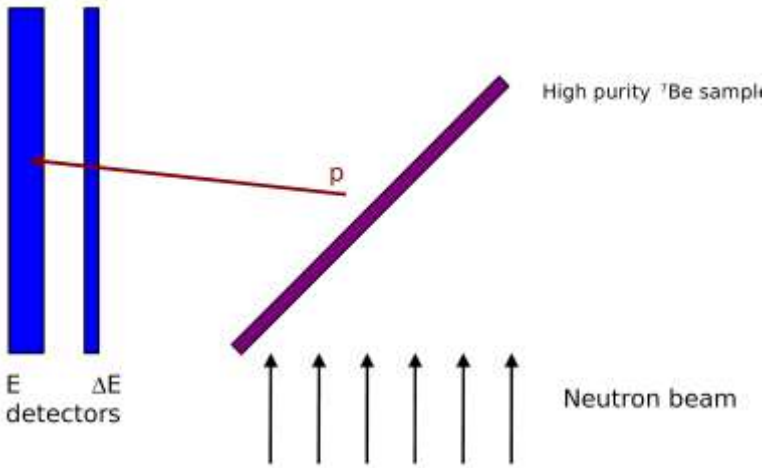
T. Kawabata et al., Phys. Rev. Lett. 118, 052701, 2017

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

$n + {}^{7}Be \longrightarrow {}^{8}Be^{*} \longrightarrow p + {}^{7}Li \quad Q \sim 1.64$ MeV

Detection and identification of protons of 1.4 MeV and 1 MeV

Silicon telescope (@Univ. of Lodz) @n_TOF-EAR2.

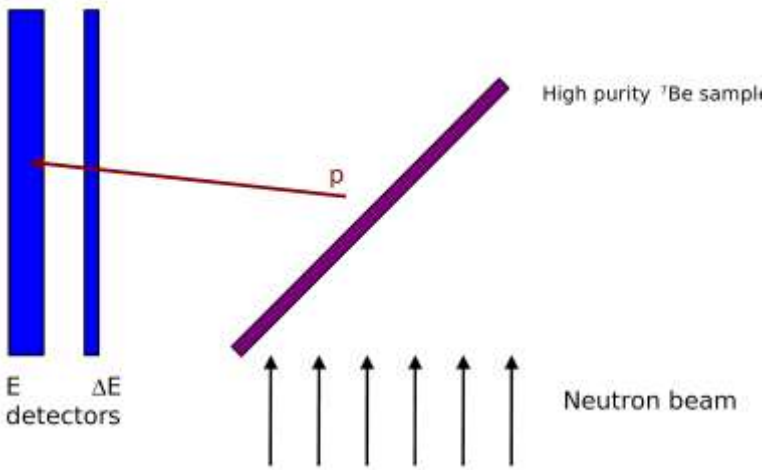


$^{7}Be(n,p)^{7}Li$ measurement

$n + {}^{7}Be \dashrightarrow {}^{8}Be^{*} \dashrightarrow p + {}^{7}Li \quad Q \sim 1.64$ MeV

Detection and identification of protons of 1.4 MeV and 1 MeV

Silicon telescope (@Univ. of Lodz) @n_TOF-EAR2.



1 GBq high purity sample needed

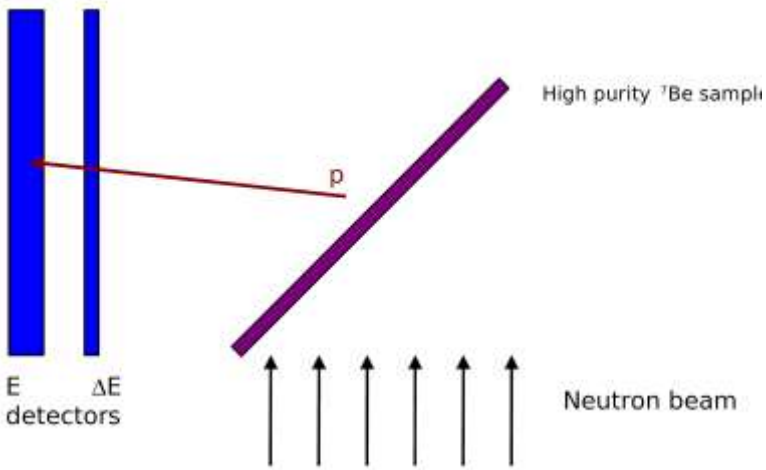
(Chemical separation not sufficient)

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

n + ^{7}Be ----> ^{8}Be* ----> p + ^{7}Li Q ~ 1.64 MeV

Detection and identification of protons of 1.4 MeV and 1 MeV

Silicon telescope (@Univ. of Lodz) @n_TOF-EAR2.



1 GBq high purity sample needed

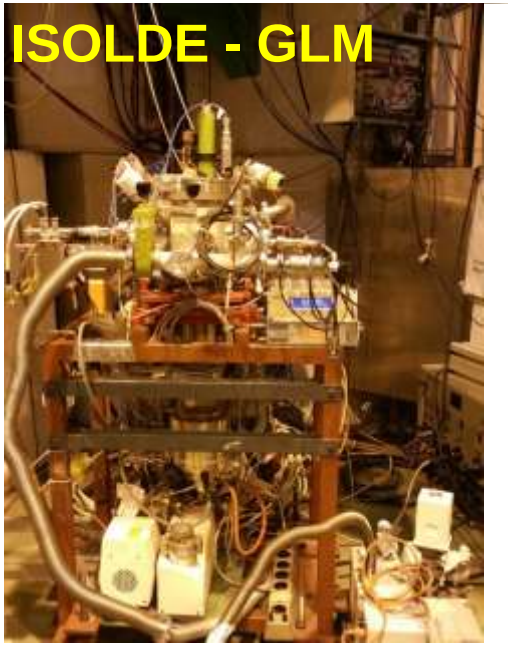
(Chemical separation not sufficient)

- **First joint n_TOF-ISOLDE experiment**
- **First time ever measurement of a neutron induced reaction cross-section using a target produced with a radioactive beam.**

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

A three steps experiment:

- Extraction of 200 GBq from water cooling of SINQ spallation source at PSI.
- Implantation of 30 keV (~45 nA) ^{7}Be beam on suited backing using ISOLDE-GPS separator (and RILIS).
- Measurement at n_TOF-EAR2 using a silicon telescope (20 and 300 μm, 5x5 cm^2 strip device).

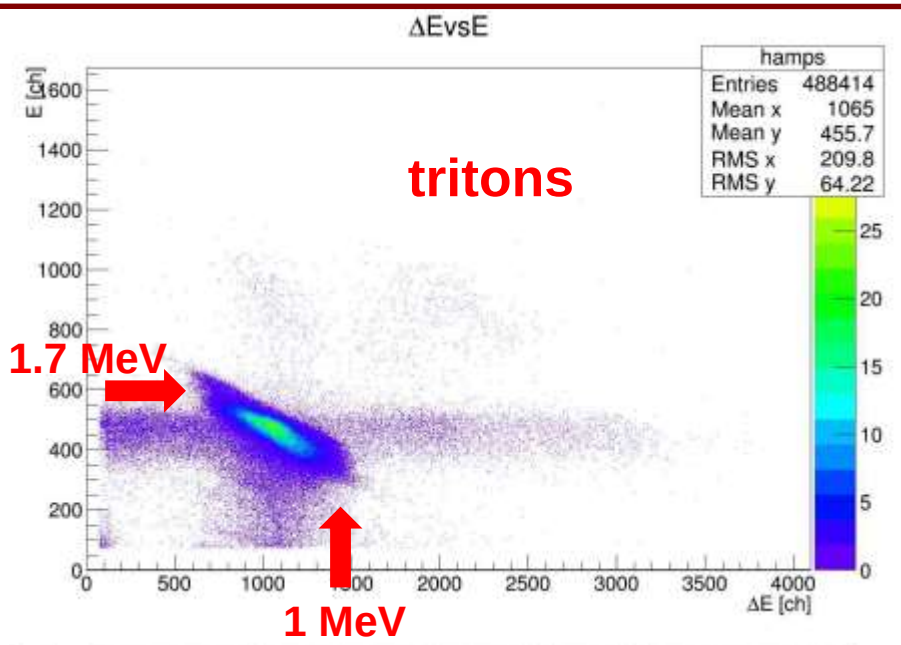


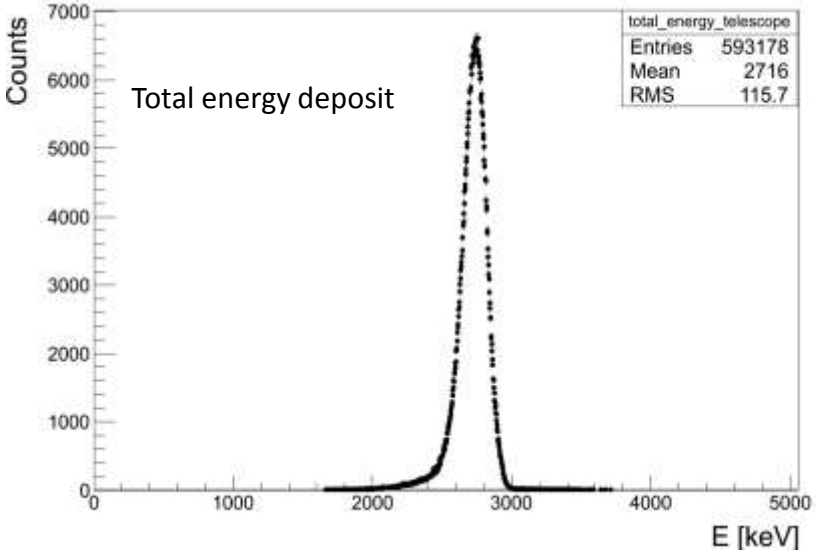
^{7}Be(n,p)^{7}Li measurement

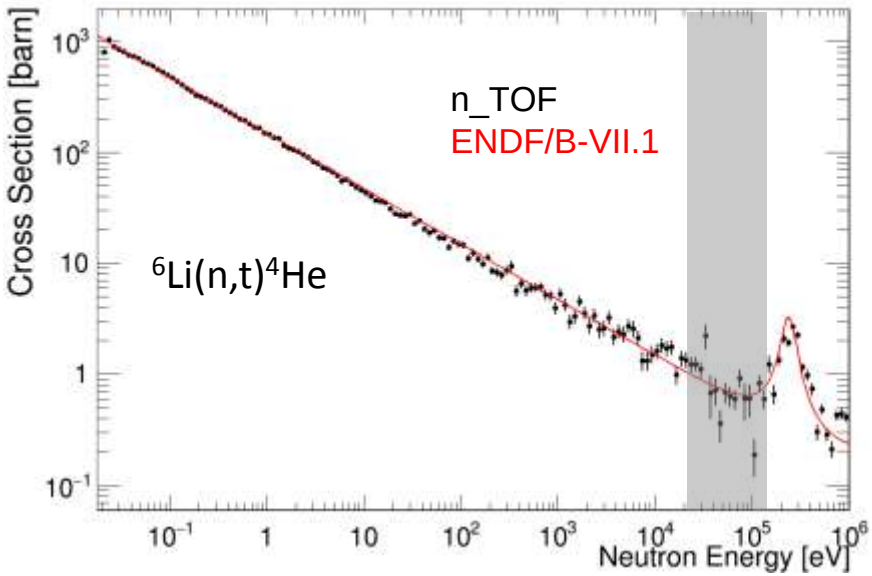
The detection system was characterized using α-source and the well-known ^{6}Li(n,t)^{4}He reaction.

n + ^{6}Li ----> ^{7}Li* ----> t + ^{4}He

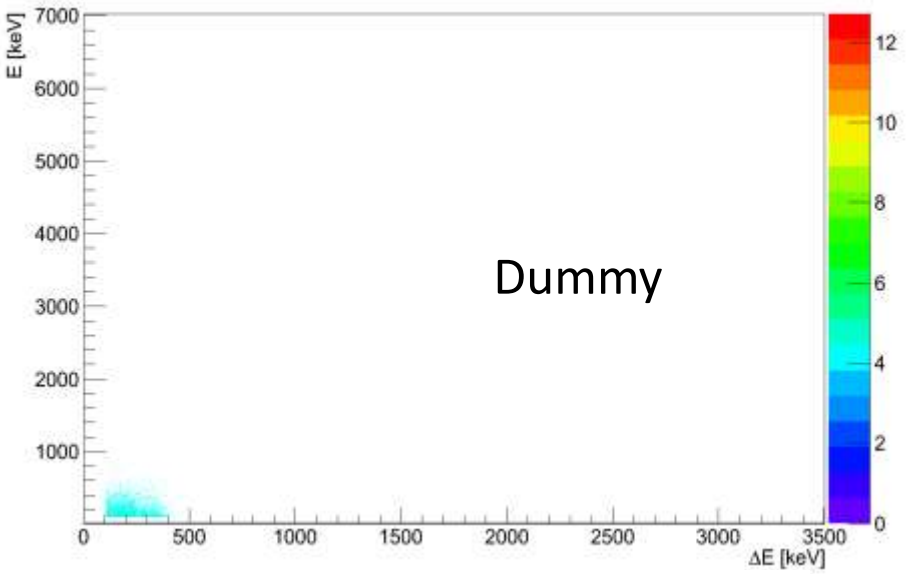
Q = 4.78 MeV

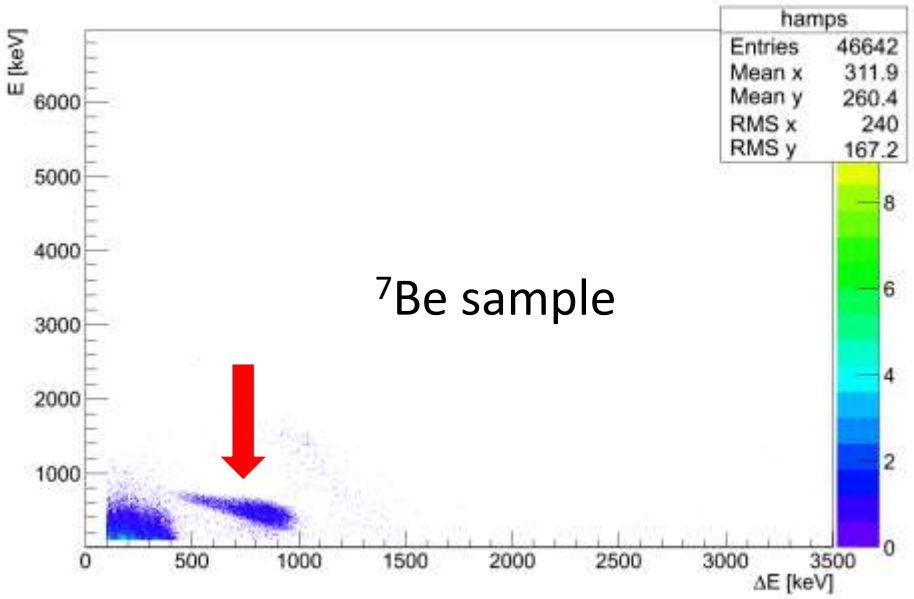


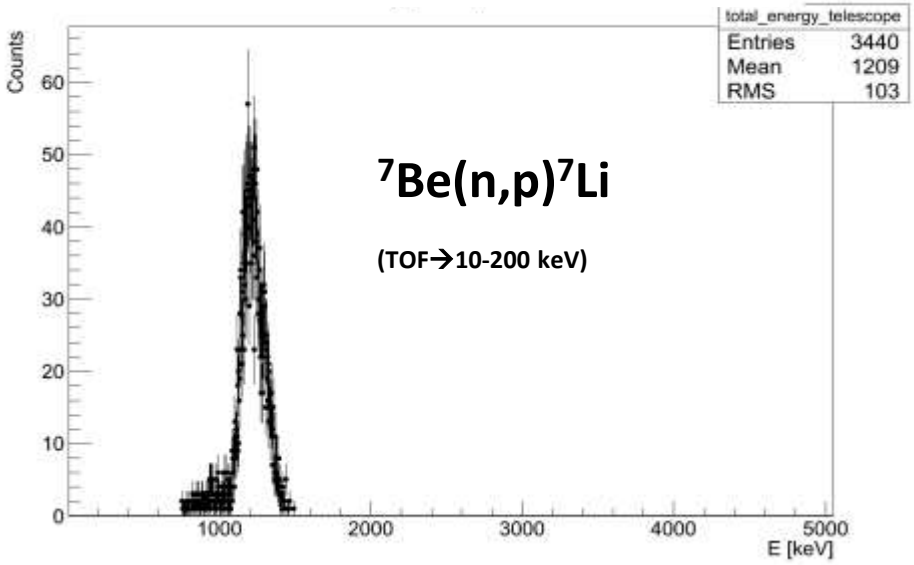


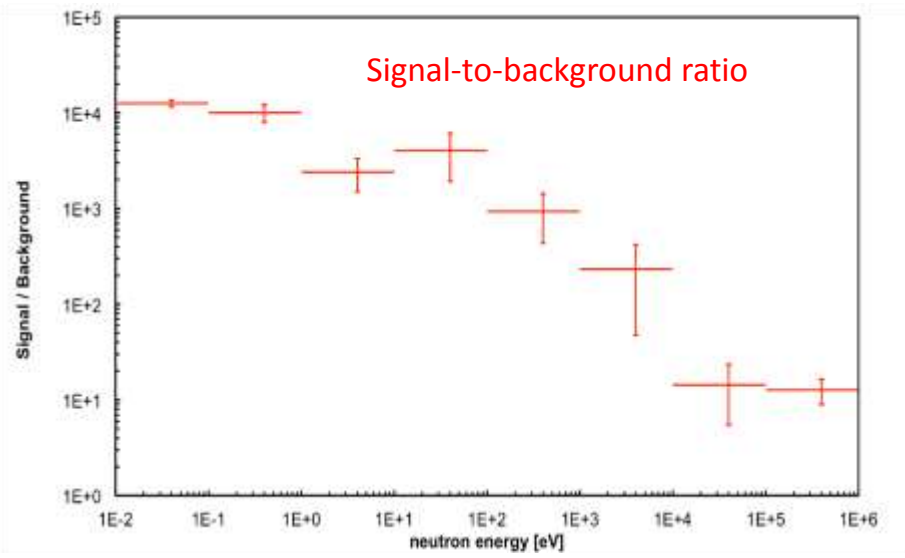


^{7}Be(n,p)^{7}Li measurement preliminary results





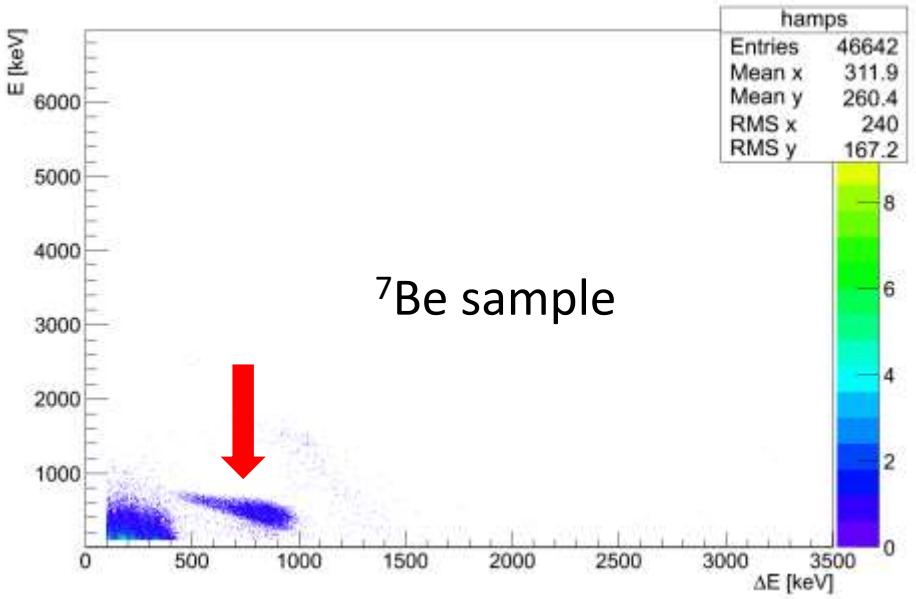


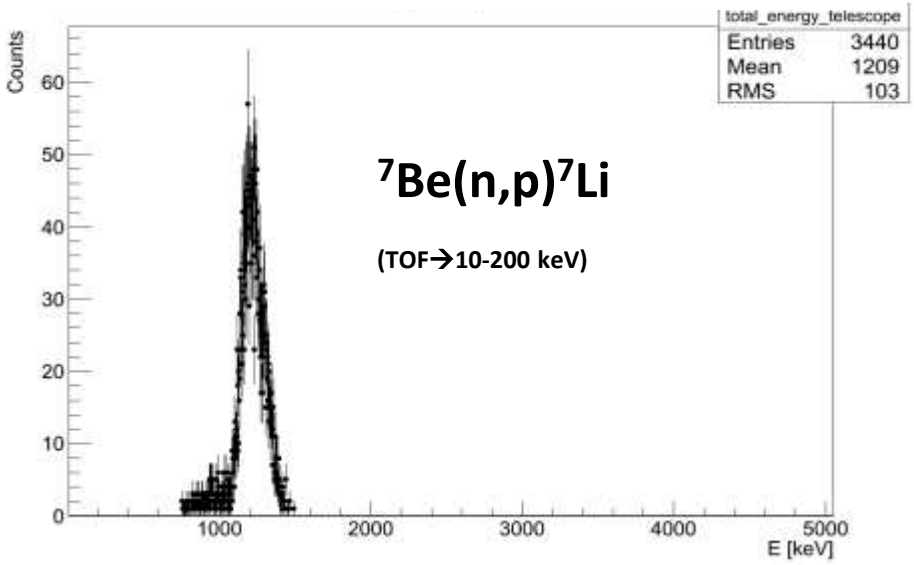


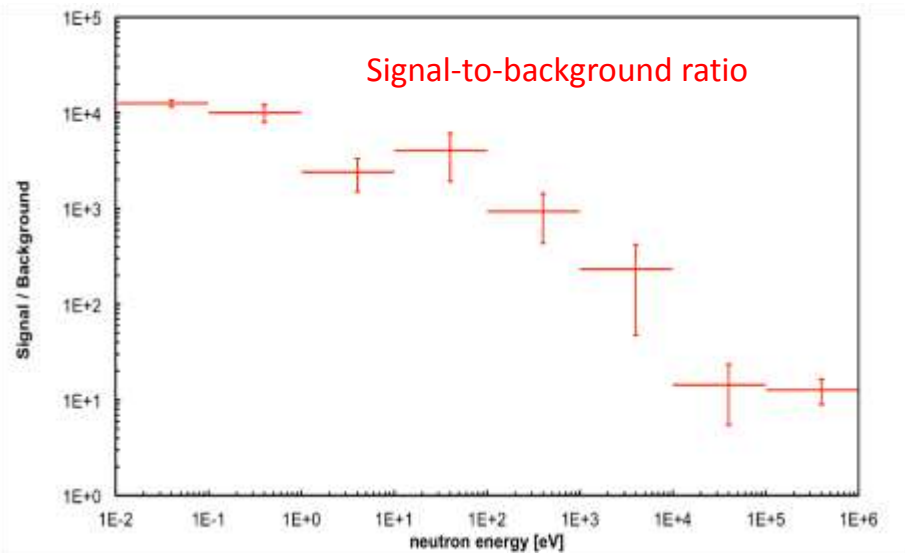
^{7}Be(n,p)^{7}Li measurement preliminary results

First time ever direct measurement of ^{7}Be(n,p) reaction in the range of interest for Big Bang Nucleosynthesis.

Stay tuned…







Conclusions and Perspectives

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

• **^{7}Be(n,α)^{4}He cross-section has been measured for the first time in a wide energy range**, using **n_TOF-EAR2** neutron beam and two samples prepared at **PSI**. The results obtained for this measurement reveal that the reaction rate currently used in BBN calculation requires substantial revision. The CLiP gets worse!

• The **^{7}Be(n,p)^{7}Li** cross-section measurement has been performed at **n_TOF-EAR2**, using a **1.1 GBq** pure sample implanted at **ISOLDE**. Preliminary results from the **^{7}Be(n,p)^{7}Li** cross-section measurement are more than extremely encouraging, **already proving that a final answer on the role of this reaction in BBN can be provided by this experiment.**

Thank you for your kind attention