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

M. Barbagallo, N. Colonna, A. Musumarra, J. Andrejewski, L. Cosentino, E. Maugeri, J. Perkowski, B. Langhans, M. Mastromarco, A. Gawlik, D. Schumann, A. Mengoni, P. Finocchiaro F. Kappeler, L. Damone, A. Pappalardo, O. Aberle, S. Heinitz, R. Dressler, E. Chiaveri and the **n_TOF collaboration**.

J. Schell, J. M. Correia, K. Johnston, M. Borges-Garcia, U. Koester, B. Marsh, T. Goodacre, R. Catherall, A. Bernardes, T. Stora, J. Ballof, B. Crepieux.

Isolde Workshop and Users Meeting, CERN, December 2016

Summary

- Physics Case
- The n_TOF facility
- The ^{7}Be(n,α) cross section measurement (PSI+n_TOF)
- The ^{7}Be(n,p) cross section measurement (PSI+ISOLDE+n_TOF)
- Conclusion and Perspectives

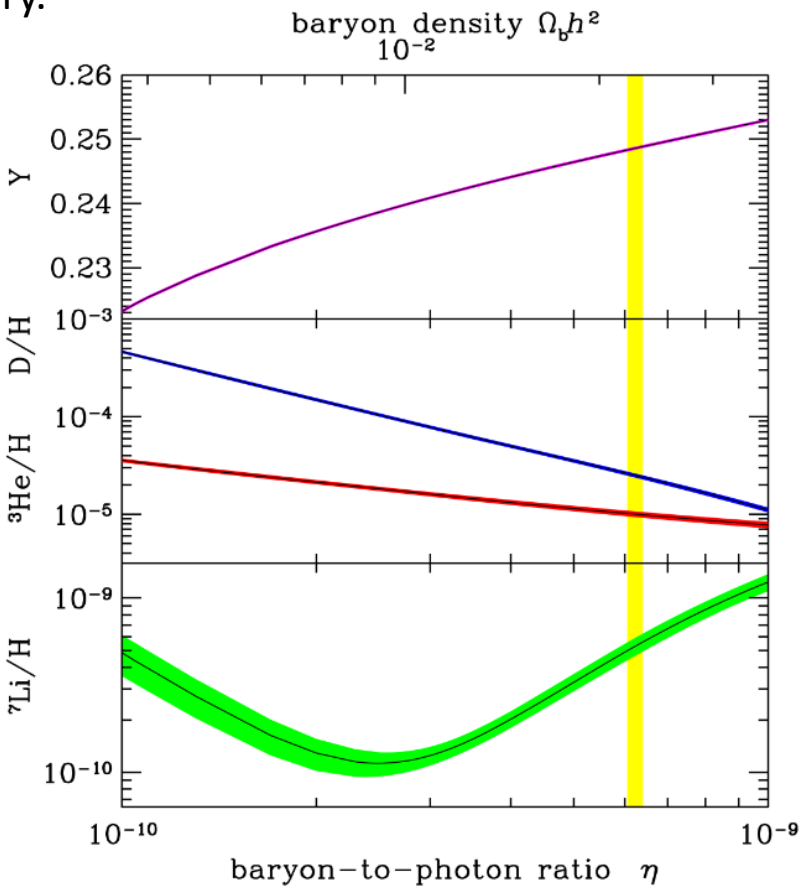
Cosmological Lithium Problem

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 in the early stage of Universe (1-200 s)

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

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



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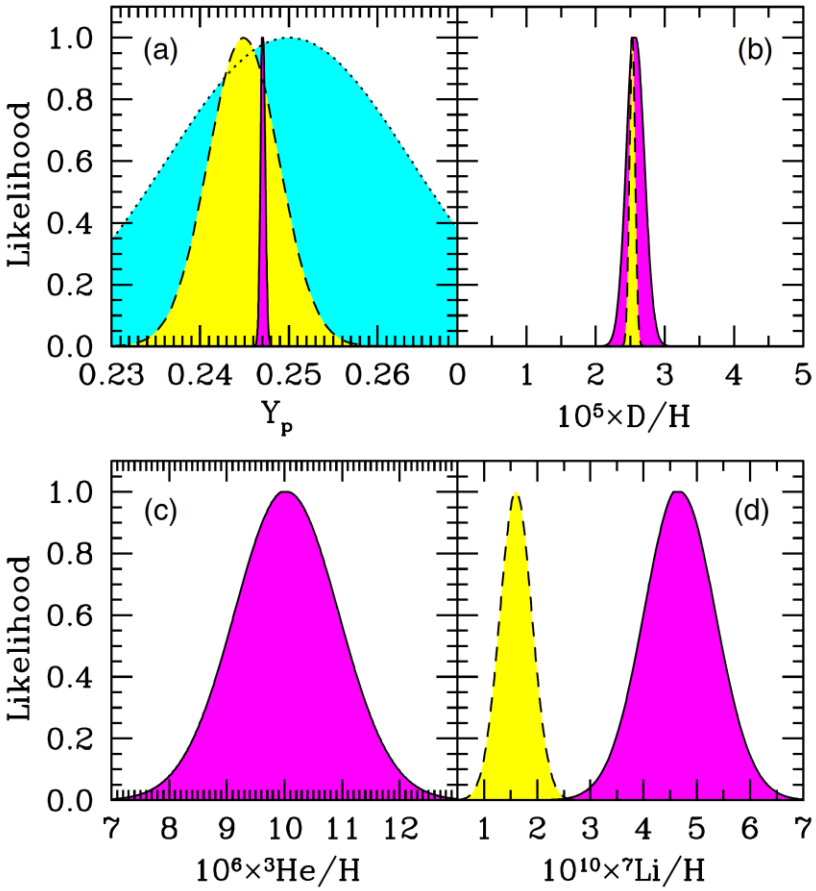


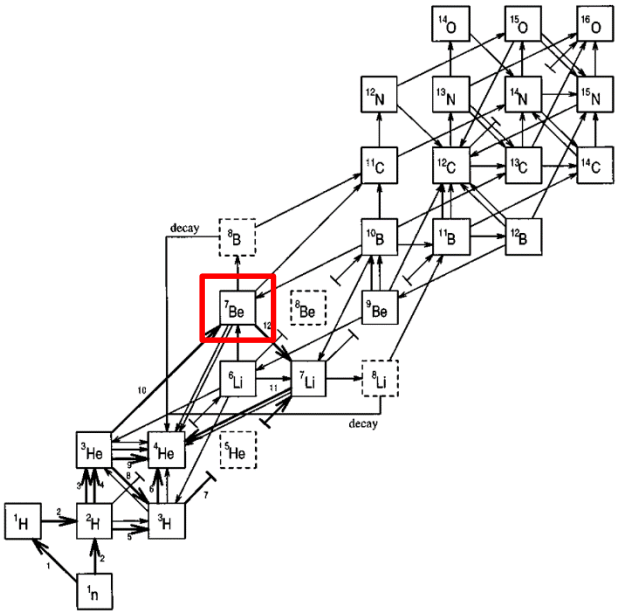
A serious discrepancy between the predicted abundance of ^{7}**Li** and value inferred by measurements (Spite et al.) → **Cosmological Lithium problem (CLiP)**

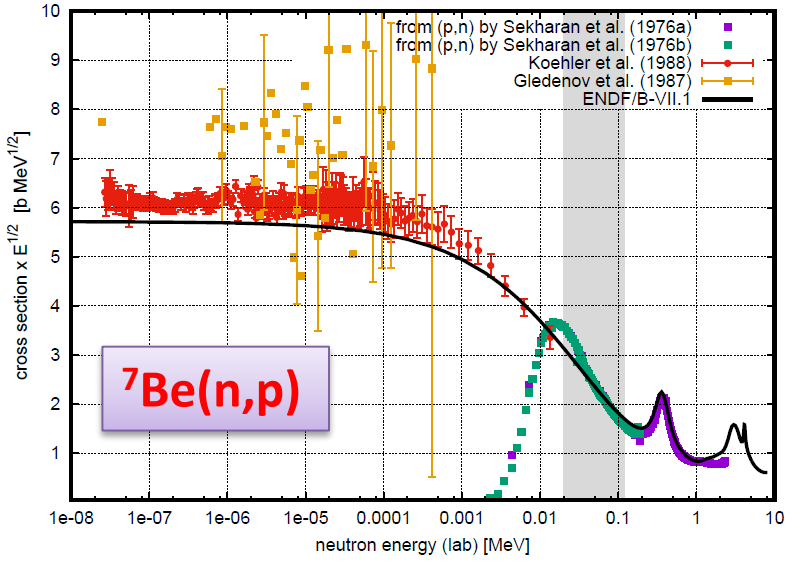
Cosmological Lithium Problem and ^{7}Be

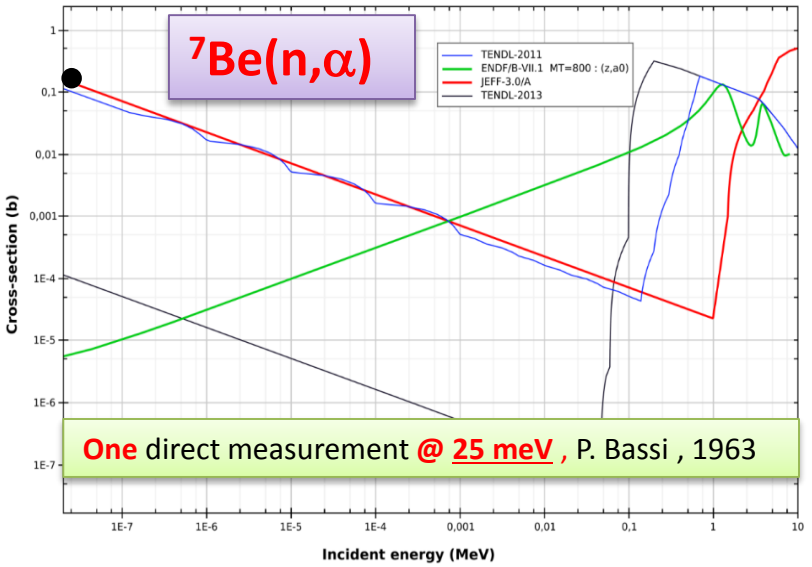
Approximately 95% of primordial ^{7}Li is produced from the **electron capture decay** of ^{7}Be ($T_{1/2}$=53.2 d).

Nuclear Physics solution to CLiP

- ^{7}Be production channels have been widely investigated and they are known with good accuracy.
- ^{7}Be decay rate in plasma(?)
- ^{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.

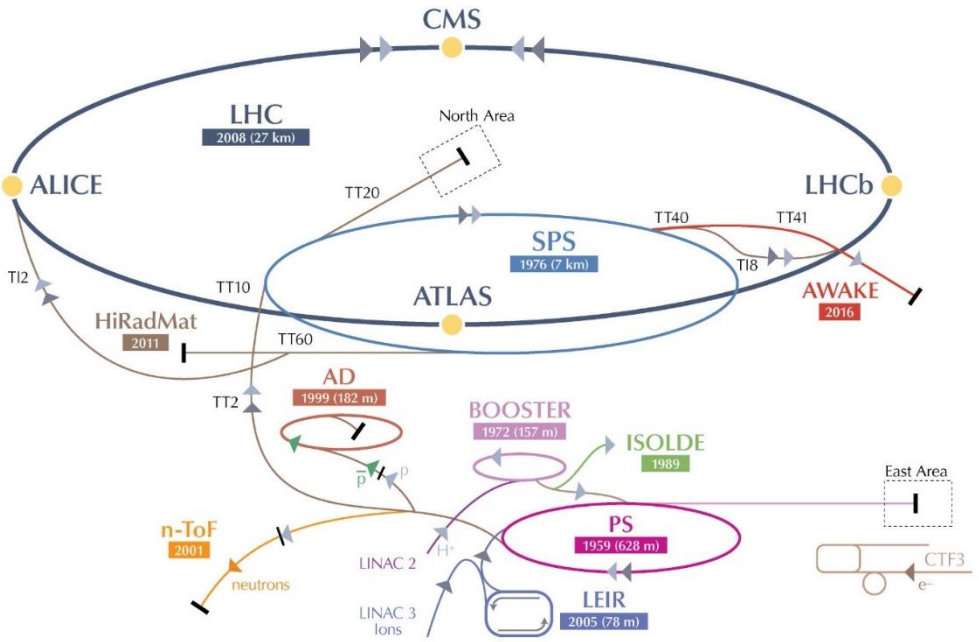






n_TOF facility at CERN

Two beam lines/experimental areas available at n_TOF, EAR1 (2001) and EAR2 (2014), with **different features.**



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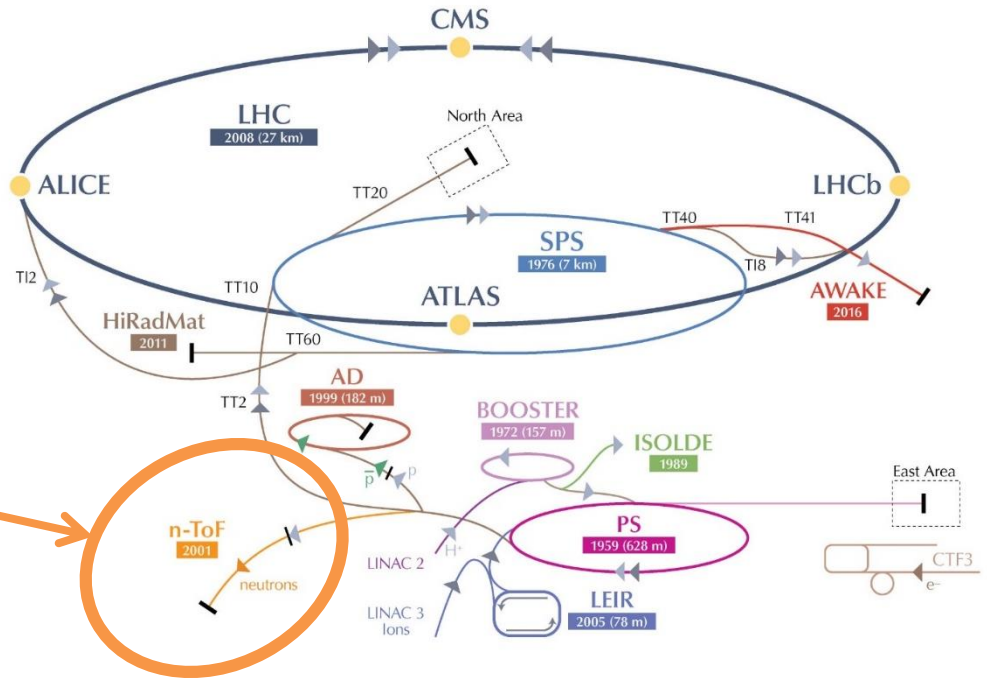
Neutron Time Of Flight facility: **n_TOF**



n_TOF program on CLiP

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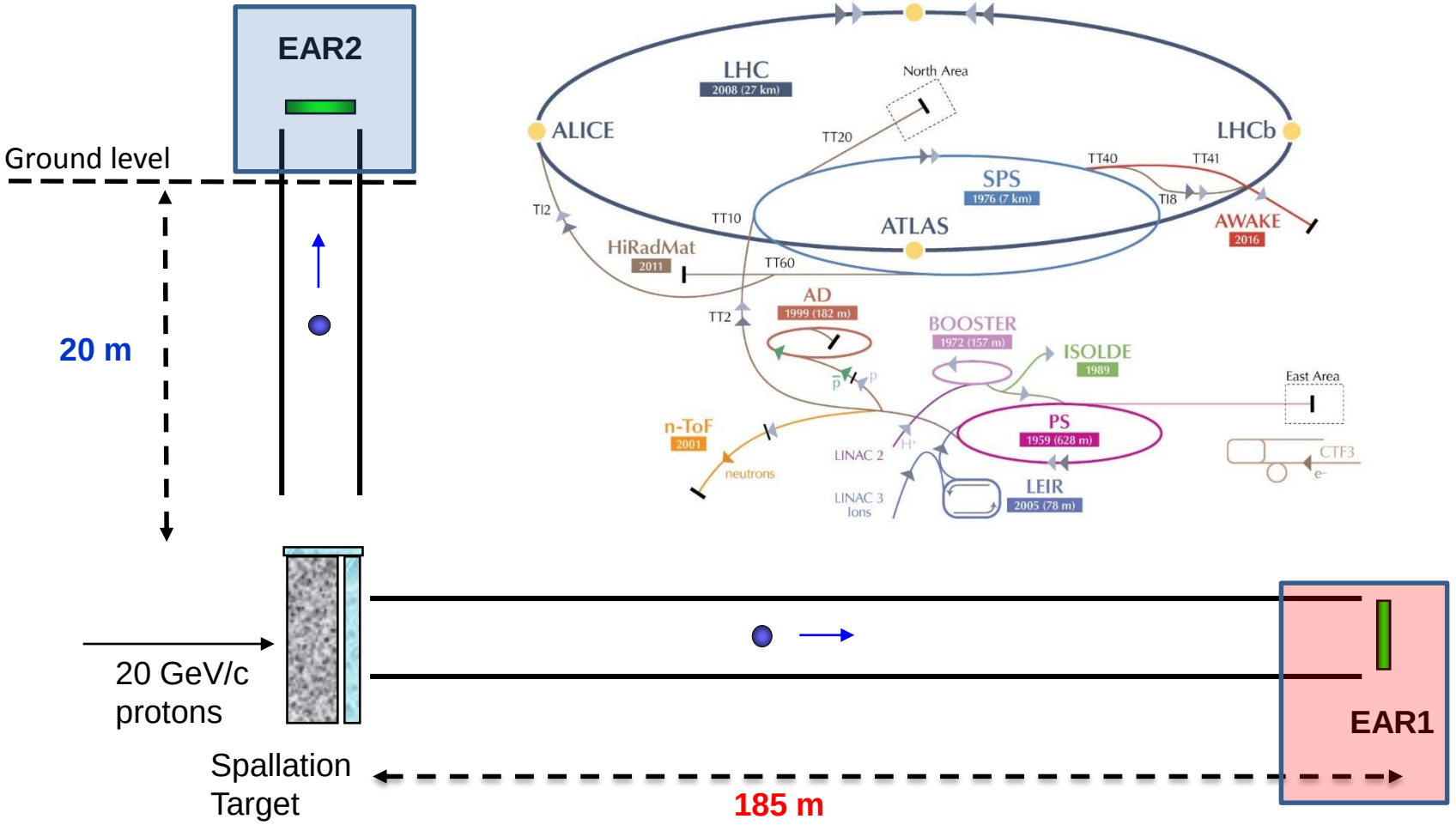

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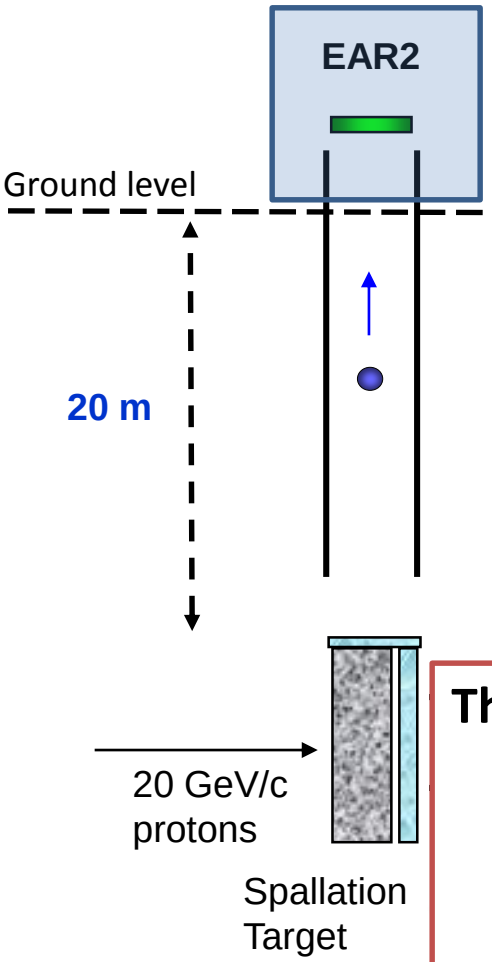

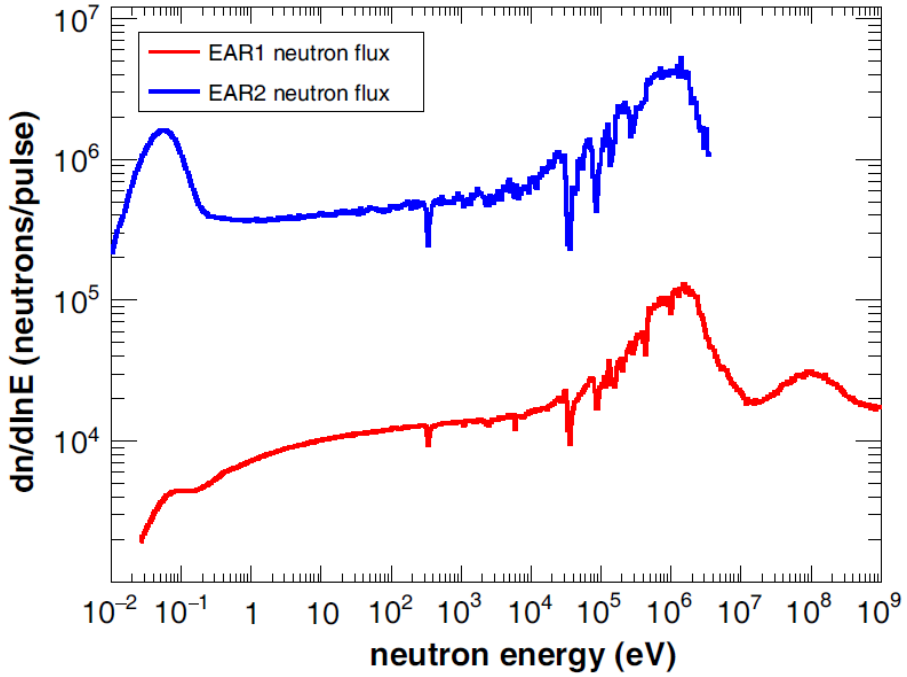

The much higher flux in EAR2 allows to:

- 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**

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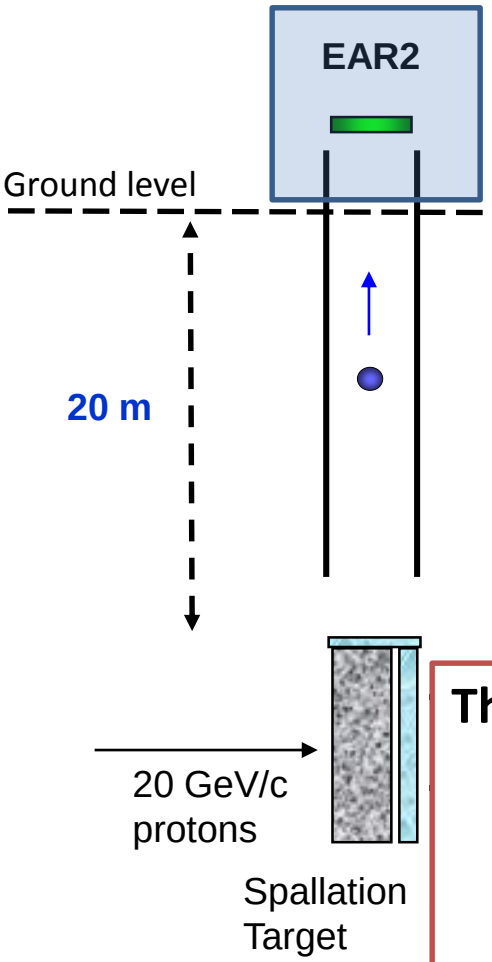

Two different measurements at n_TOF-EAR2
(M. Barbagallo et al., CERN-INTC-2014-049/INTC-P-417)

i) $n+^{7}Be \rightarrow \alpha+\alpha$ **Aug-Oct 2015**

ii) $n+^{7}Be \rightarrow p+^{7}Li$ **Apr-Jun 2016**

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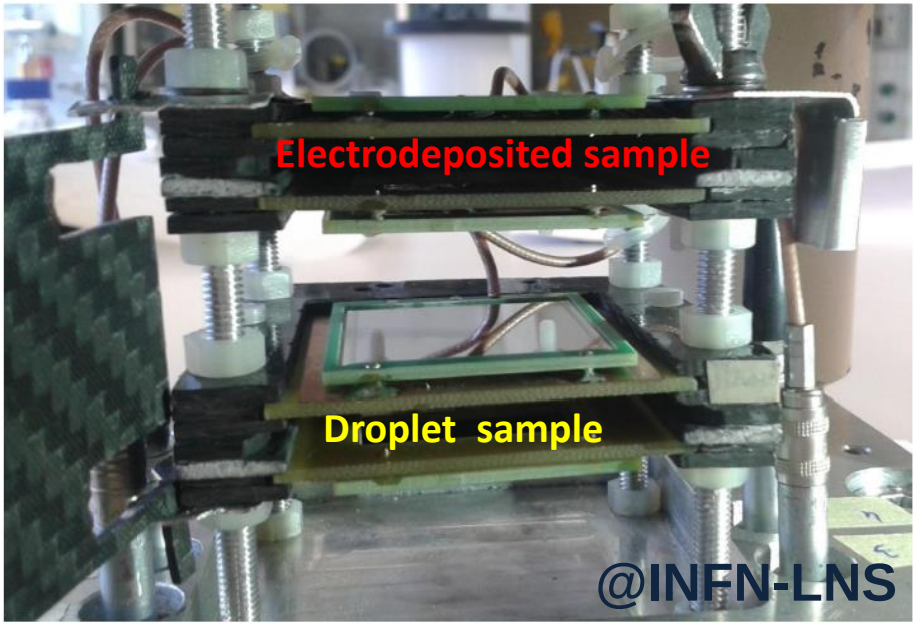
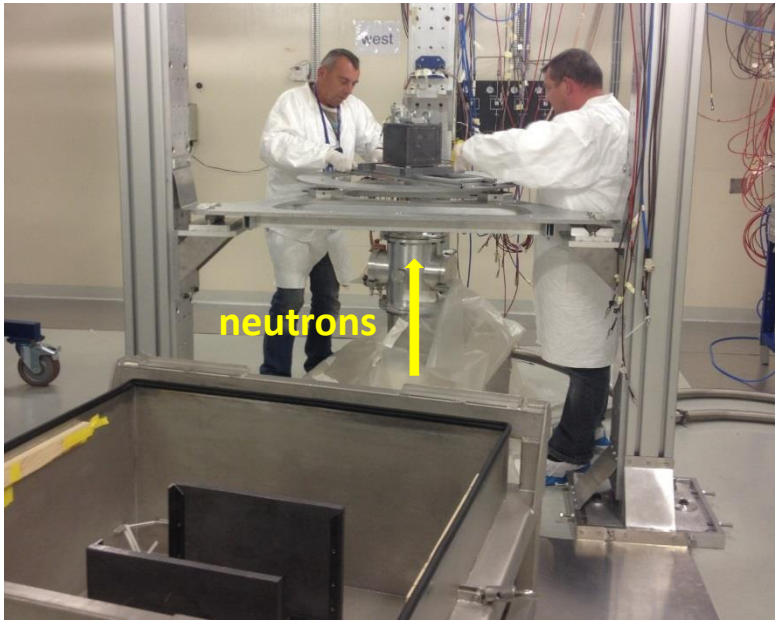
$^{7}Be(n,\gamma\alpha)^{4}He$ measurement: setup

$n + {}^{7}Be \longrightarrow {}^{8}Be^{*} \longrightarrow \alpha + \alpha\ (+\gamma)$ 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



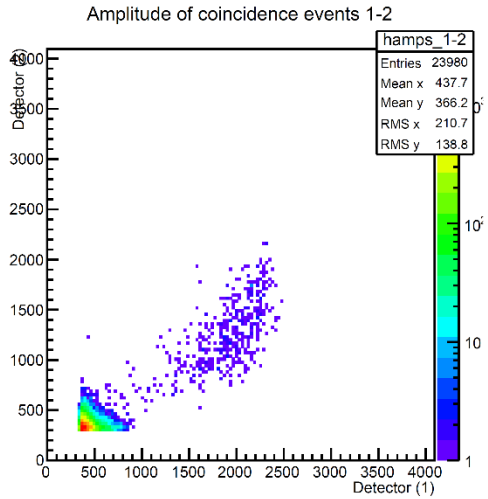


L. Cosentino et al., NIM A 830 (2016) 197-205

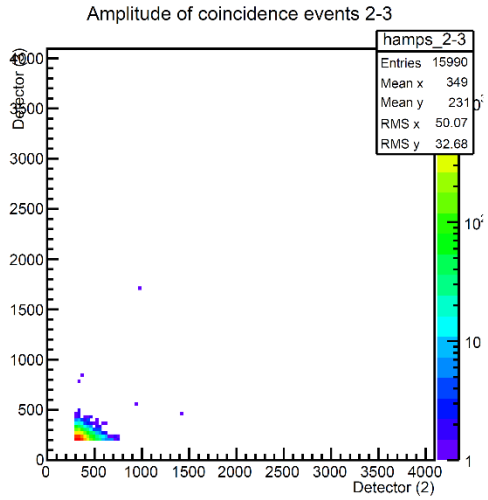
Strong rejection of background: coincidence signals, low duty cycle beam, Time-of-Flight

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

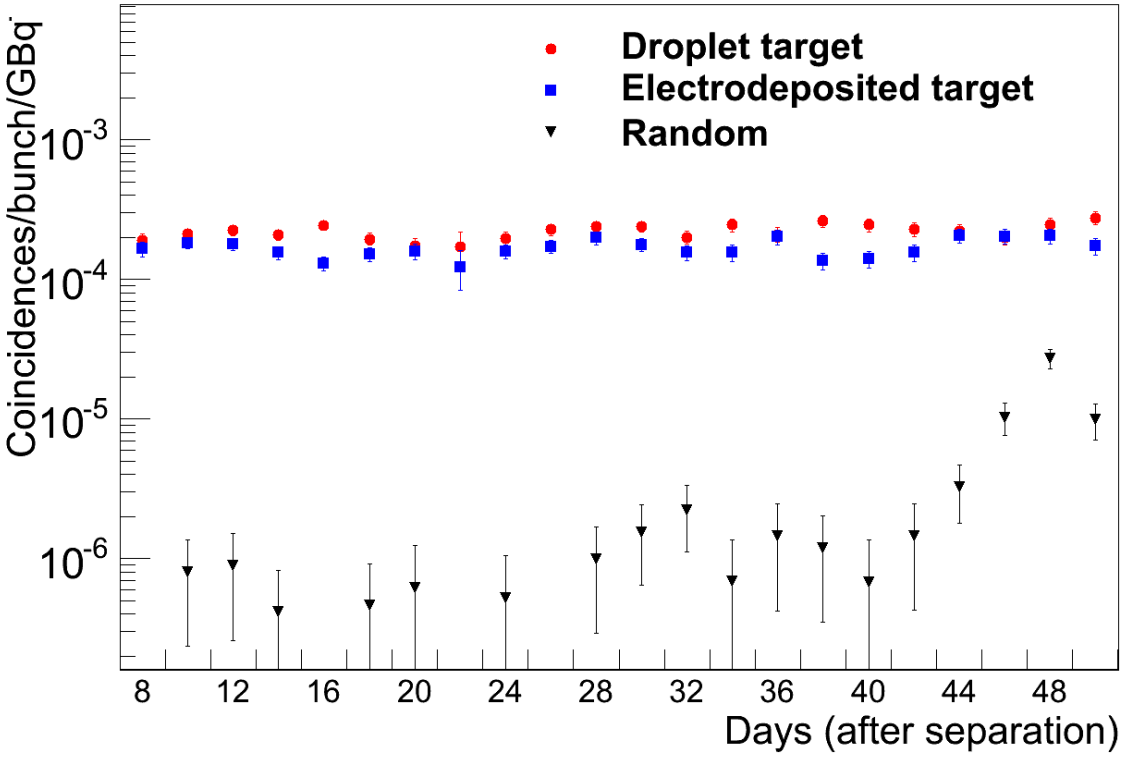
Sample



No sample



E_{dep}> 2 MeV threshold applied



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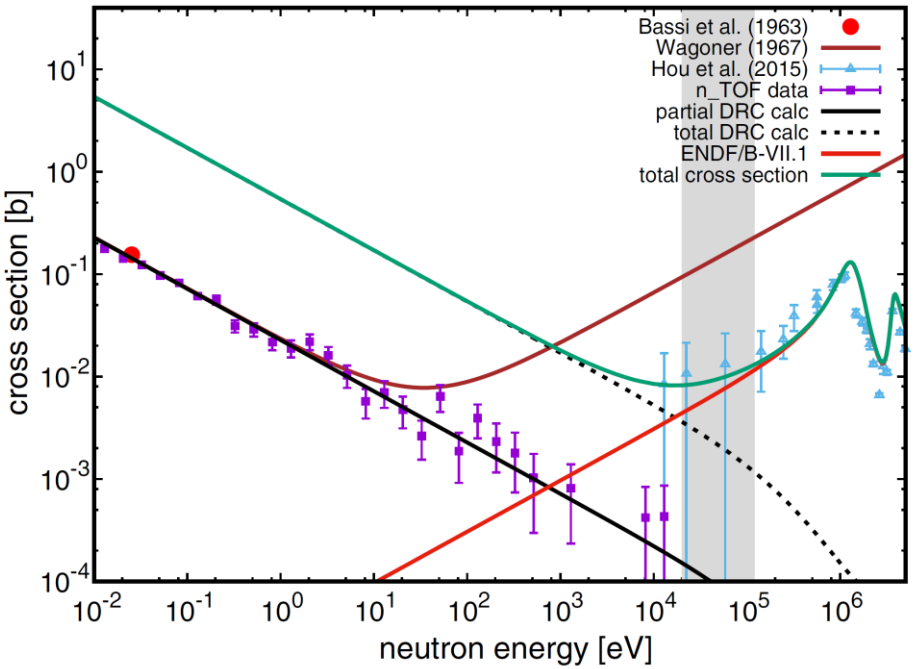
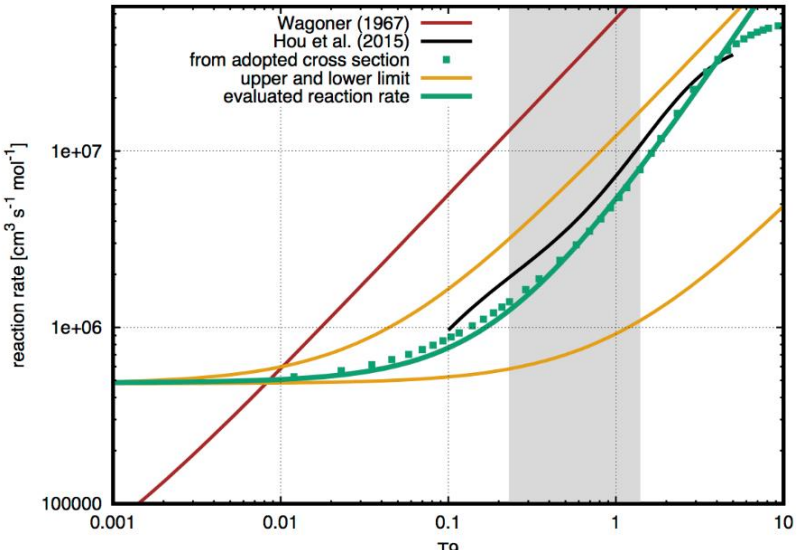
$^{7}Be(n,\alpha)^{4}He$ n_TOF results and CLiP



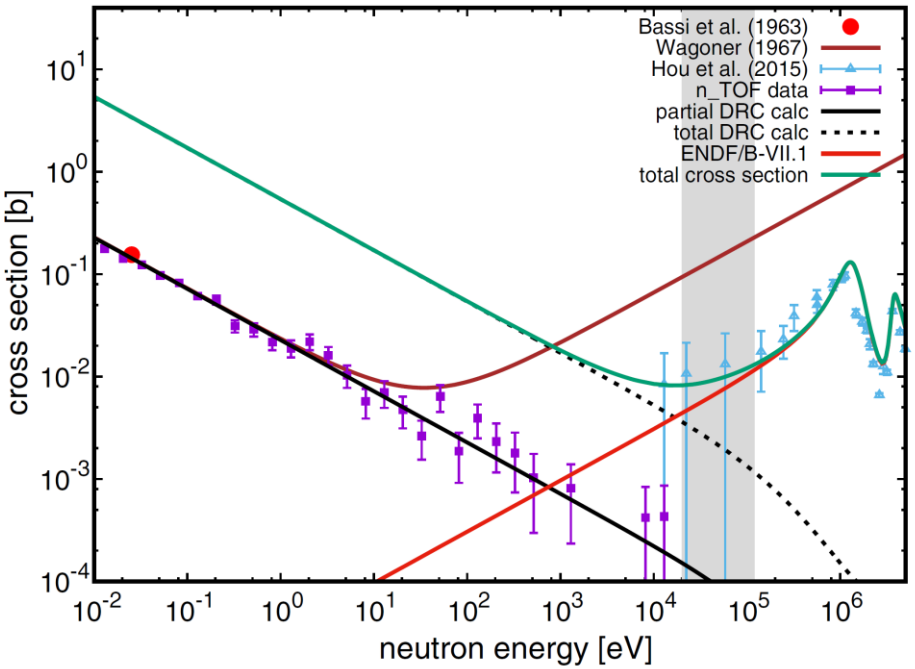


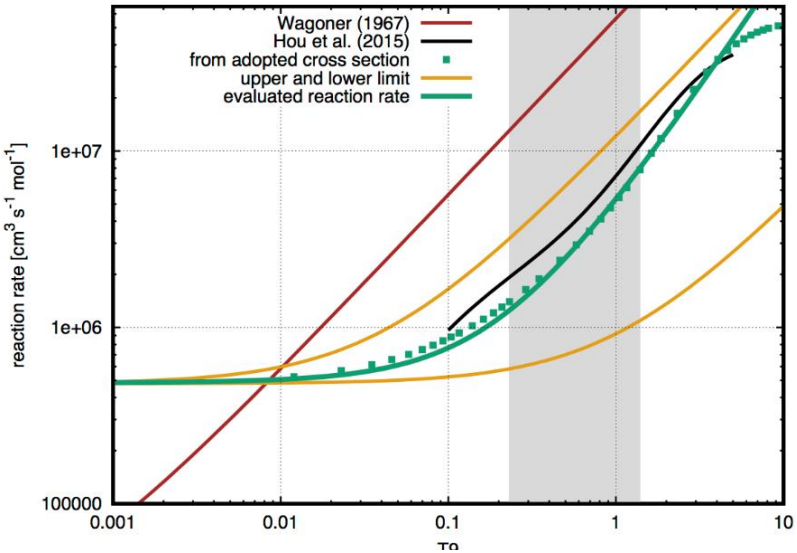
$$N_A\langle\sigma v\rangle = 4.81 \times 10^5 + 1.84 \times 10^6 T_9 + 3.03 \times 10^6 T_9^{3/2}$$

M. Barbagallo et al., Physical Review Letters 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
- http://www.astronomianews.it/index.php?p=astro_news&n=2215

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





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- http://www.astronomianews.it/index.php?p=astro_news&n=2215

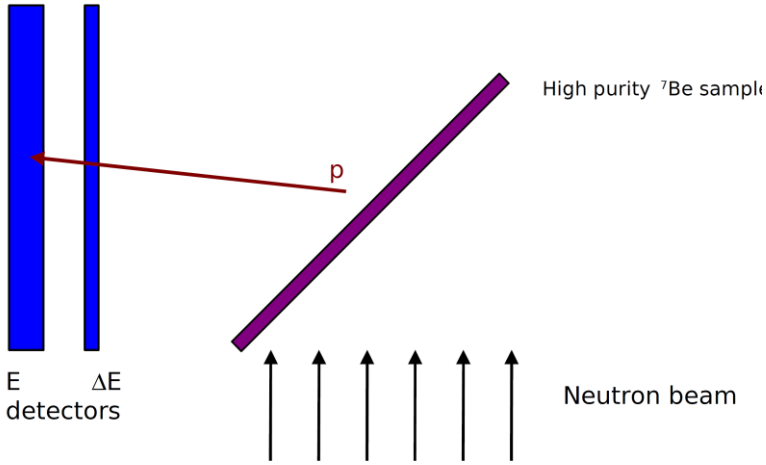
As for (n,α) measurement, the Cosmological Lithium Problem worsens!

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



1 GBq high purity sample needed

(Chemical separation not sufficient)

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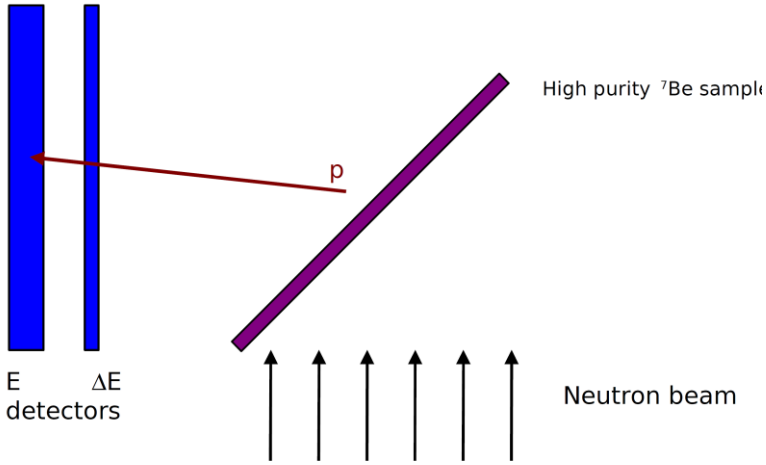

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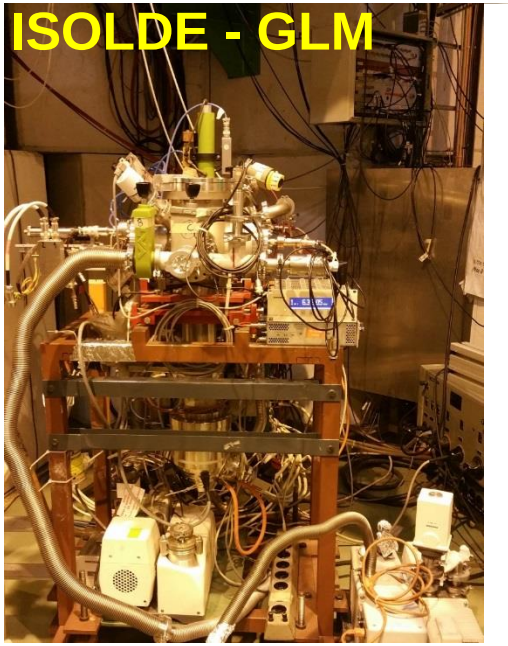
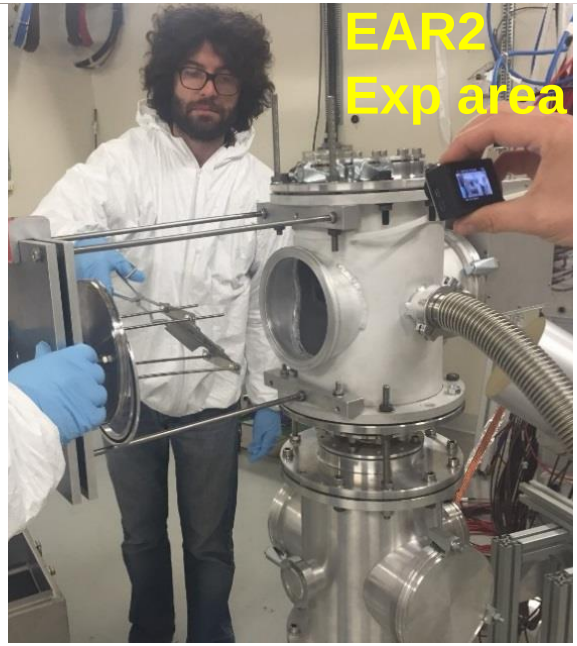
- **First joint n_TOF-ISOLDE experiment**
- **First time ever measurement of a neutron induced reaction cross-section using a target produced with a radioactive beam.**

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

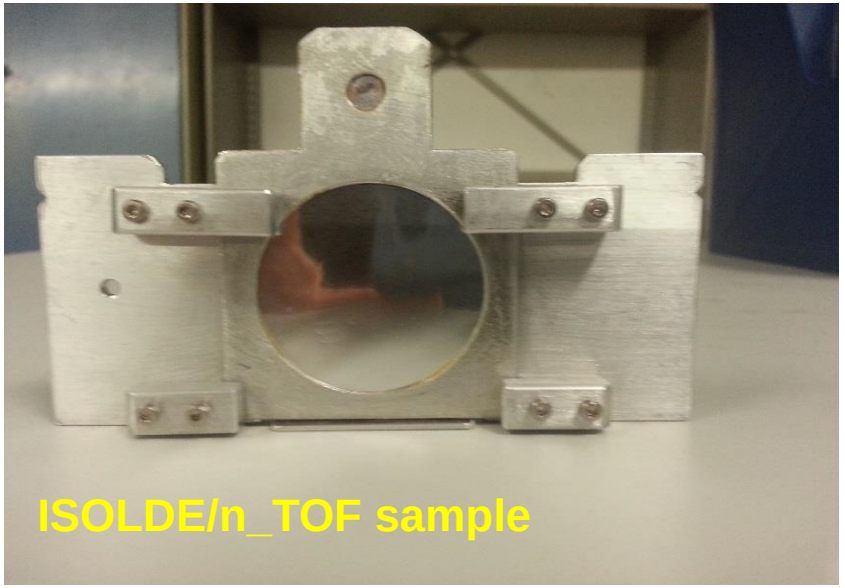
A three steps experiment:

- 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)

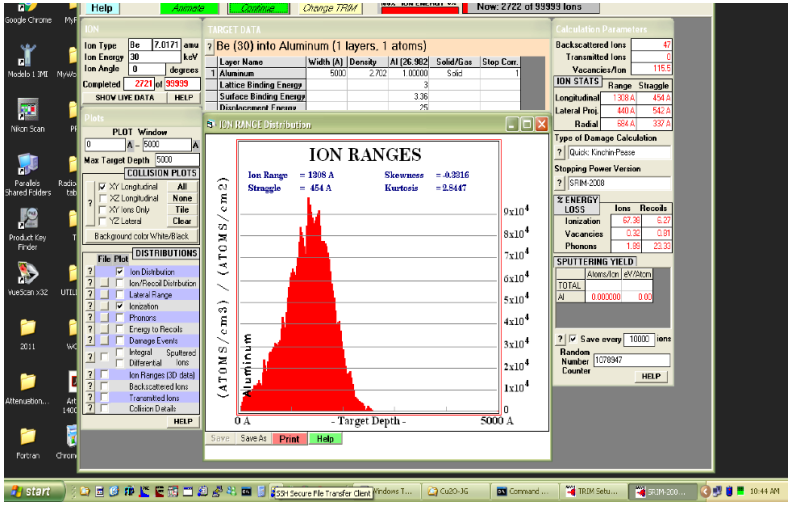




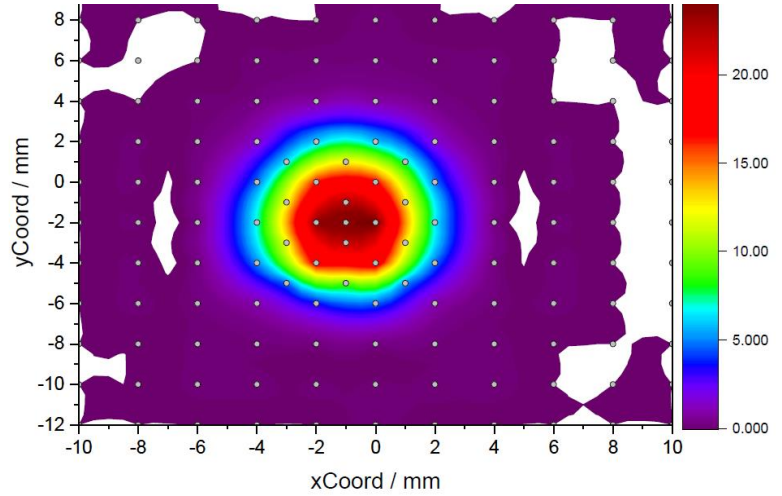
^{7}Be sample: the making of



Average implantation depth: 150 nm



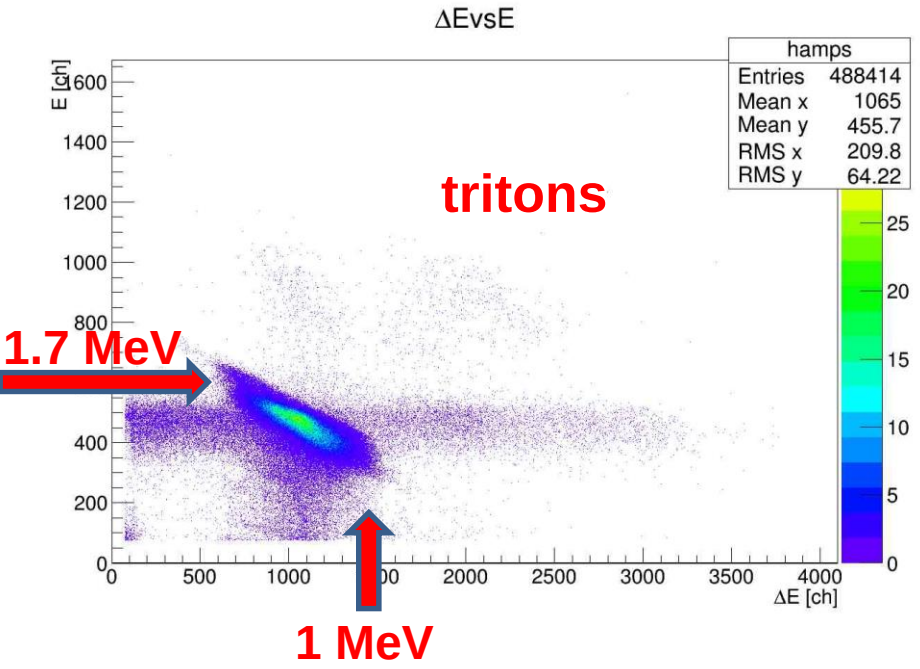
A posteriori sample characterization @PSI

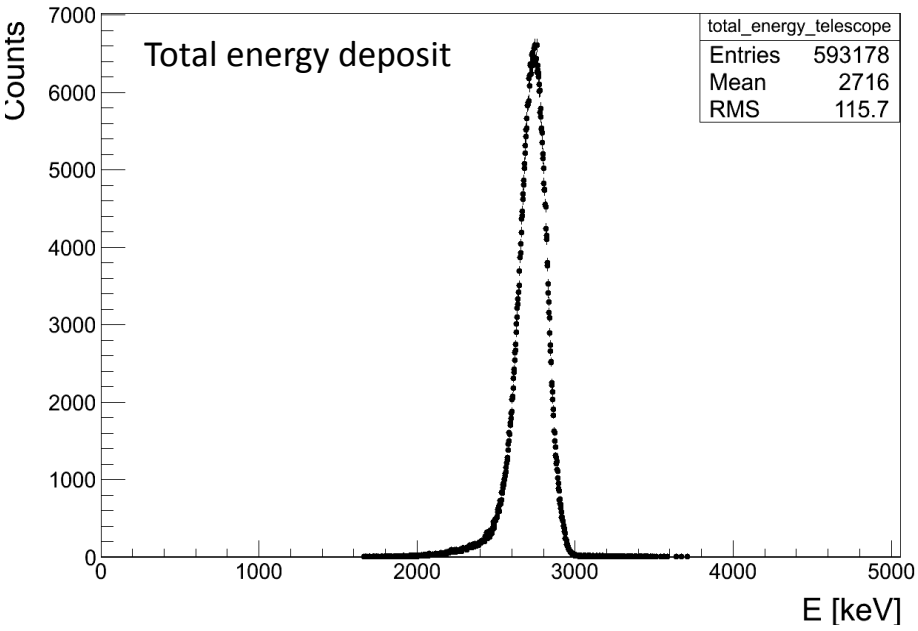


^{7}Be(n,p)^{7}Li measurement

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





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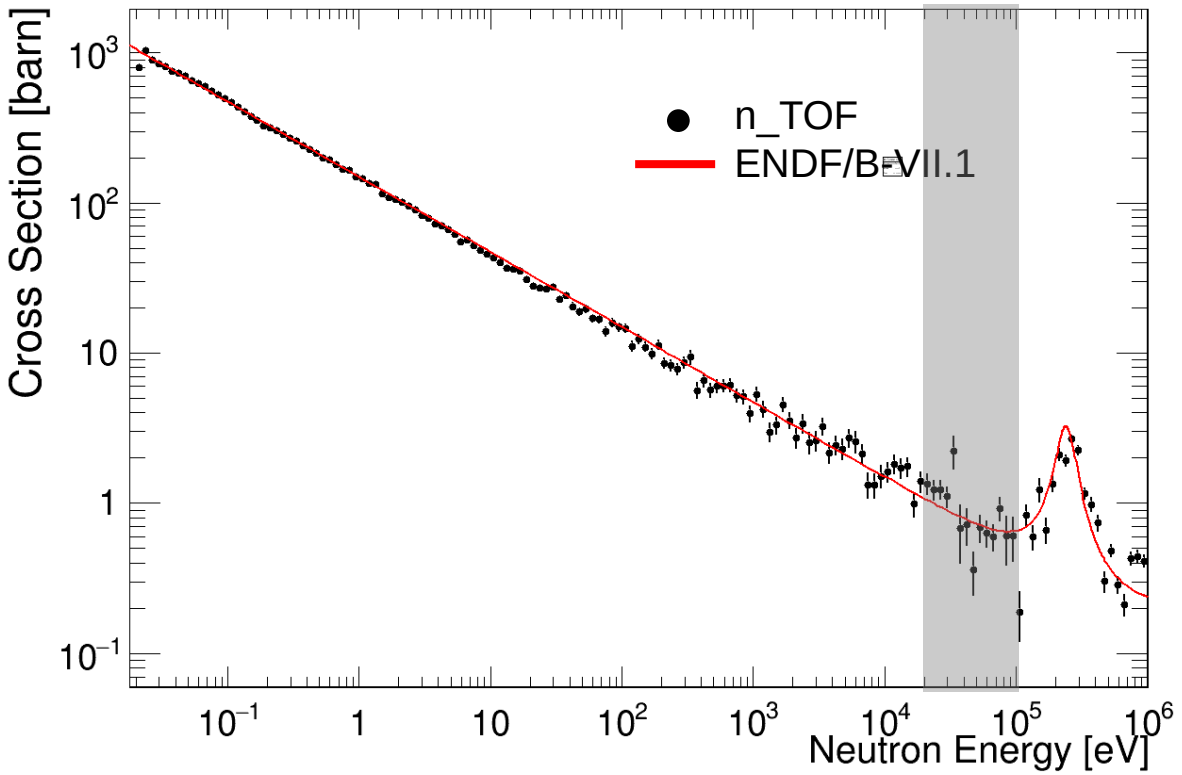
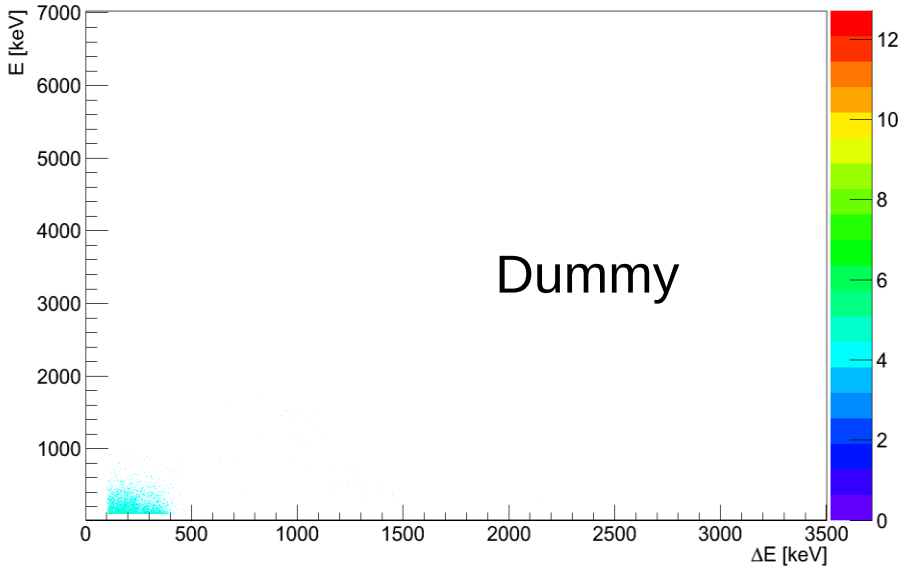
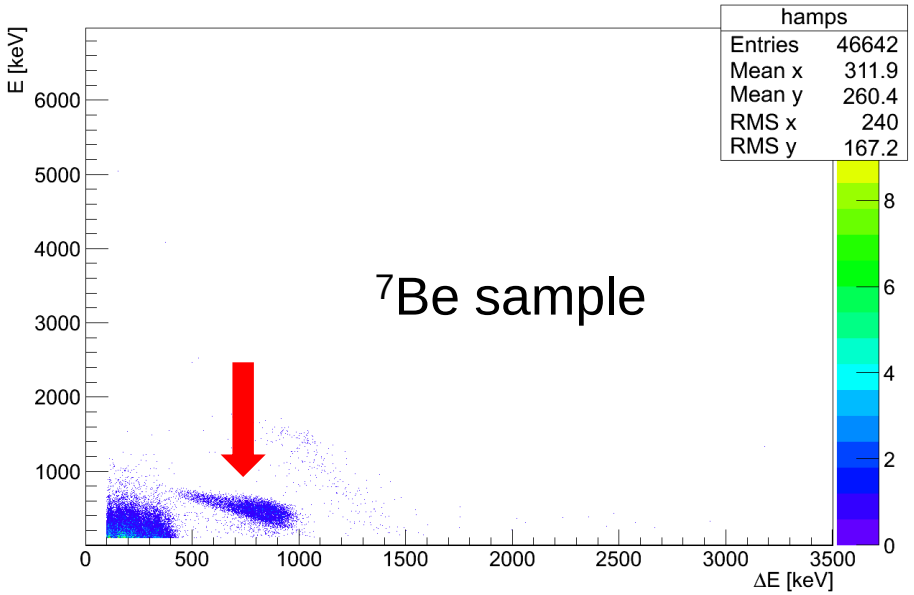
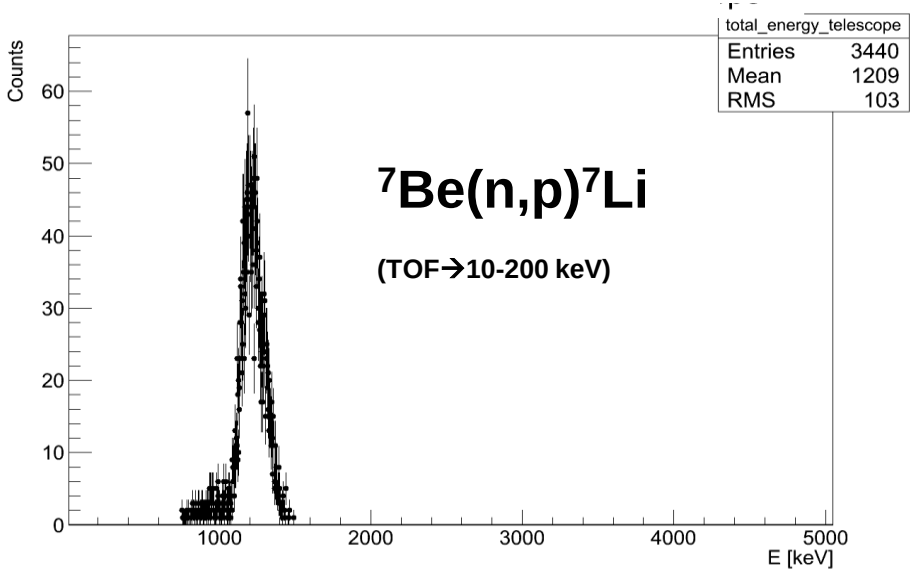


Upper energy limit for detection --> 1 MeV incident neutron energy

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

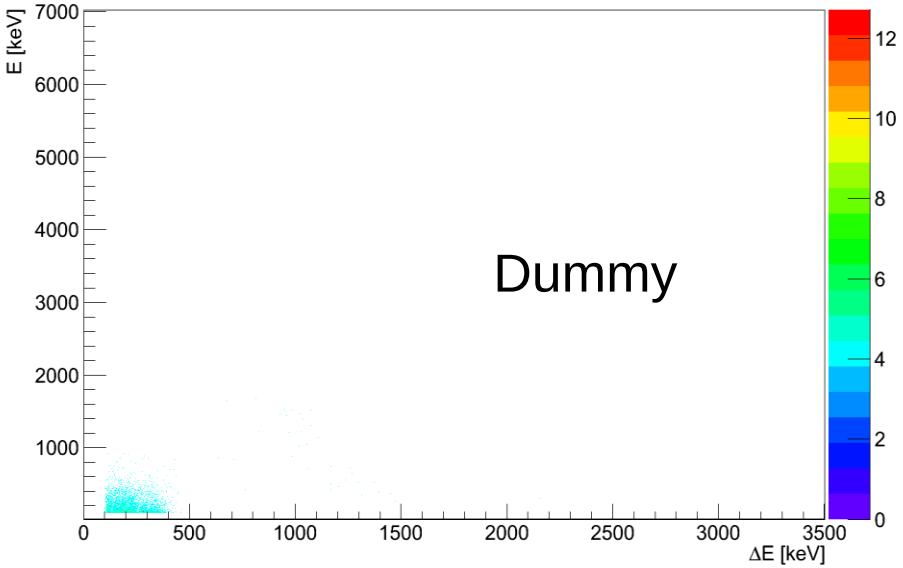


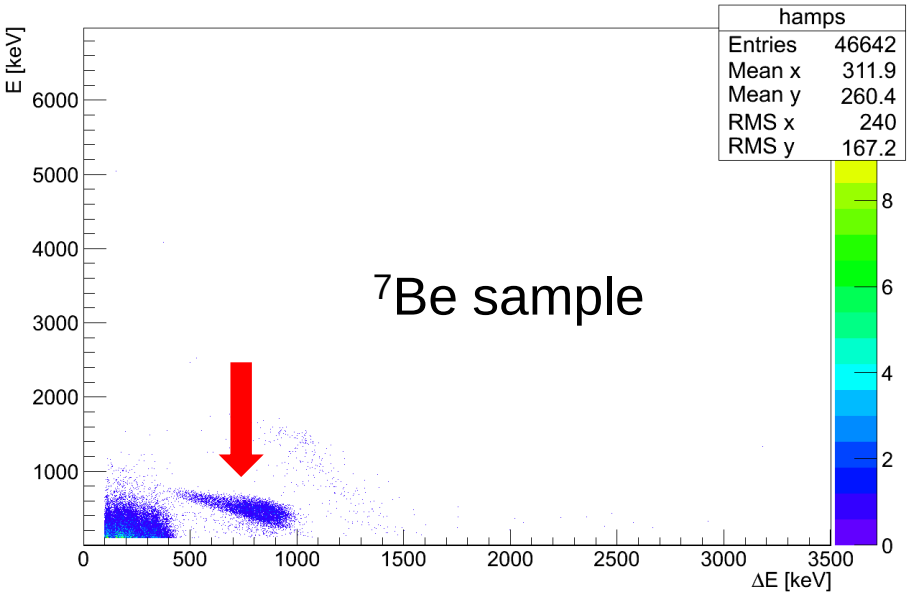


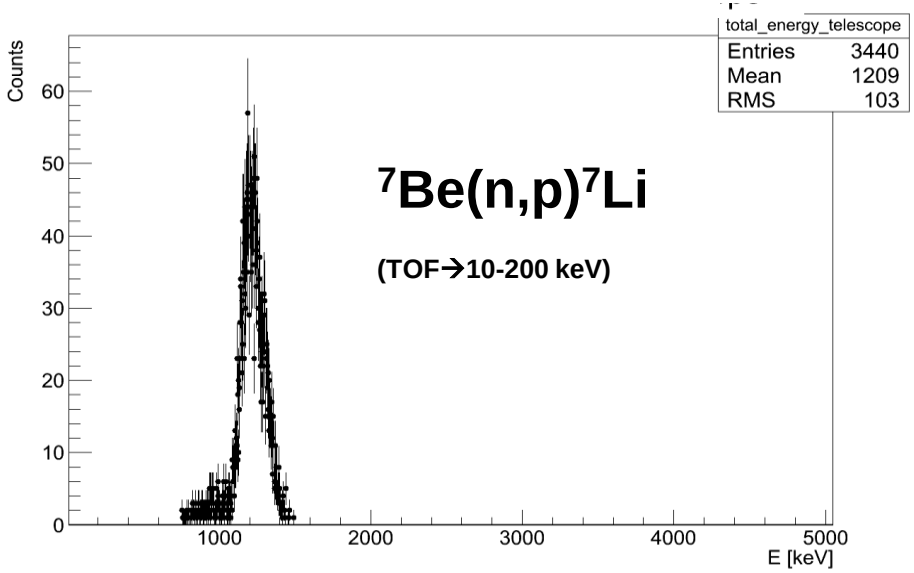


First time ever direct measurement of ^{7}Be(n,p) reaction in the range of interest for Big Bang Nucleosynthesis

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







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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 worsens!

• 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 **GLM beam line of ISOLDE**, starting from a 200 GBq ^{7}Be solution collected at **PSI.**

• 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.**

- **The best is yet to come!**

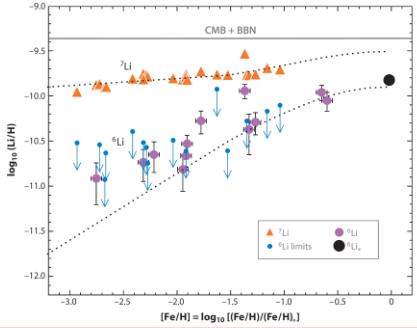
Conclusions and Perspectives

Log(Present knowledge) [a.u.]

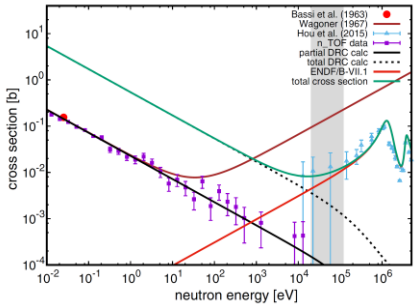
n_TOF+ISOLDE

^{7}Be(n,p), resonant states, storage ring..

Astrophysics model and observations

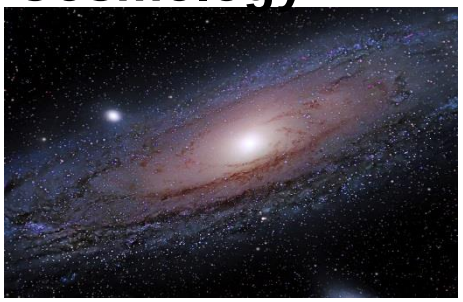


Nuclear Physics

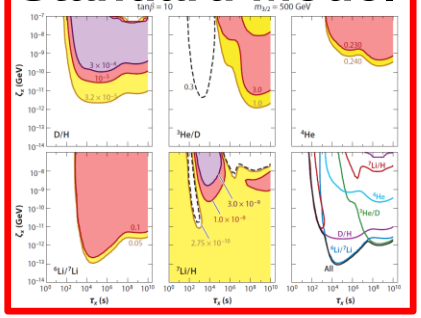


n_TOF

Non standard Cosmology



Physics beyond Standard Model



Fascination [a.u.]