(n,cp) reactions study at the n_TOF facility at CERN: results for the Cosmological Lithium problem

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

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2-CERN

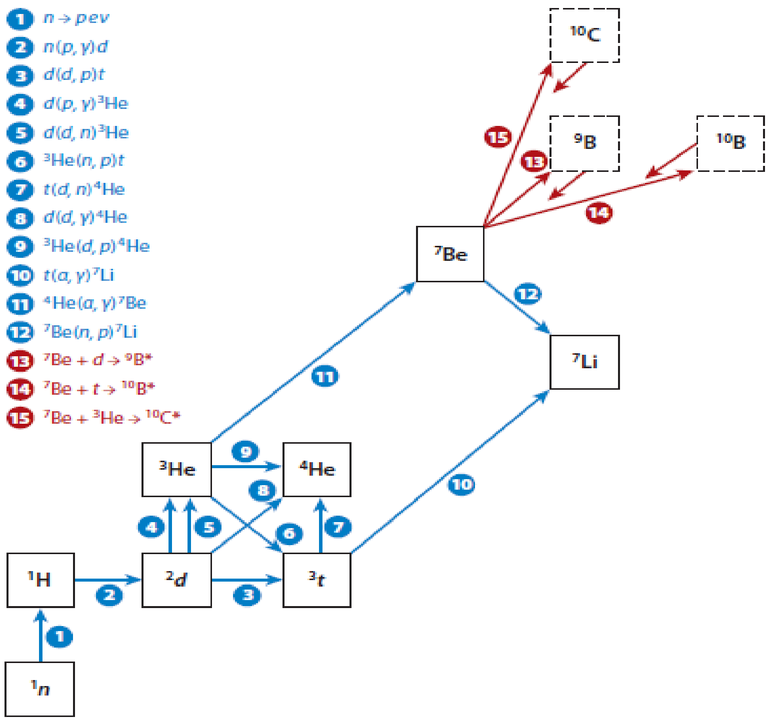
15th Varenna Conference on Nuclear Reaction Mechanisms, 11-15 June 2018, Villa Monastero, Varenna

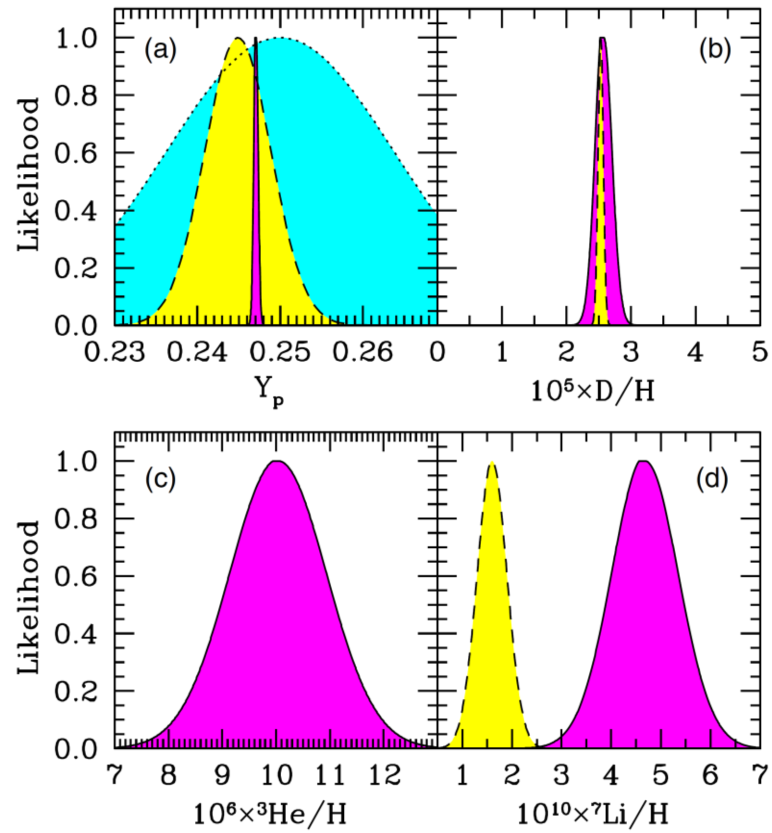
Summary

- The Cosmological Lithium Problem
- The ^{7}Be(n,α) and the ^{7}Be(n,p) cross section measurements
- Implications for Nuclear Astrophysics
- Conclusions and Perspectives

Cosmological Lithium Problem

Big Bang Nucleosynthesis successfully predicts the abundancies of light elements, i.e. D and ^4He, but…



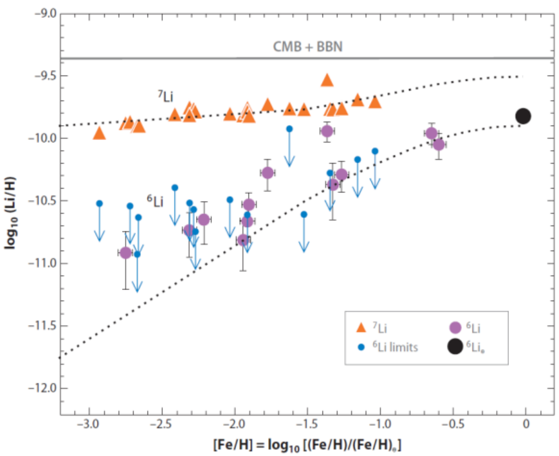


Serious discrepancy between the predicted abundance of ^7Li and the value inferred by measurements (Spite et al.) → **Cosmological Lithium problem (CLiP)**

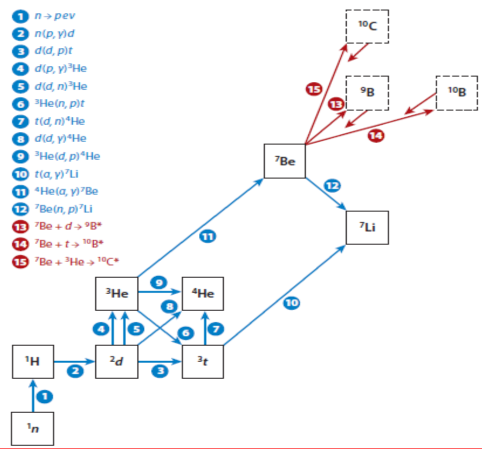
Solutions to CLiP

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

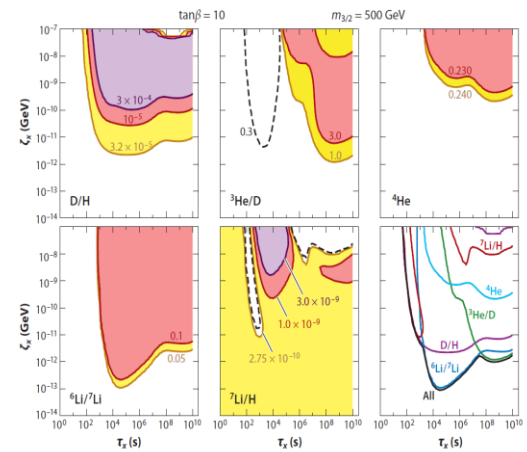
Astrophysical



Nuclear Physics



Non Standard Physics



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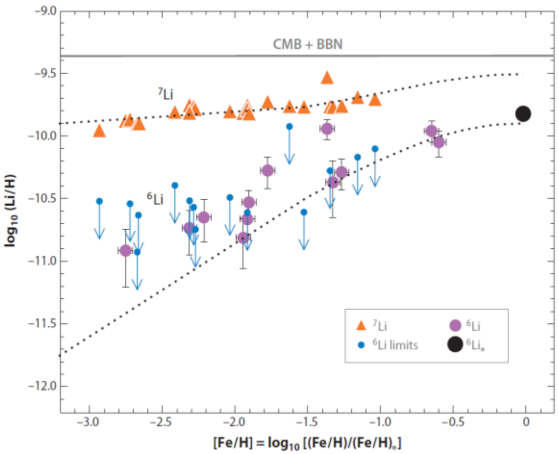

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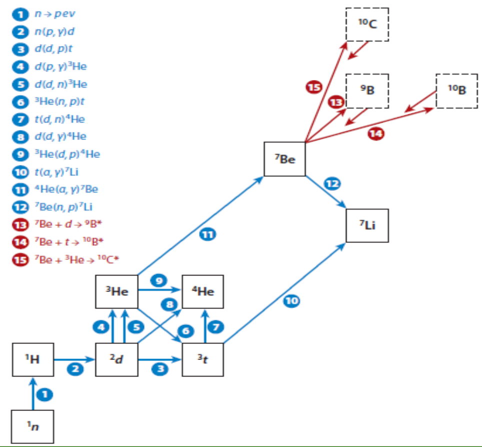

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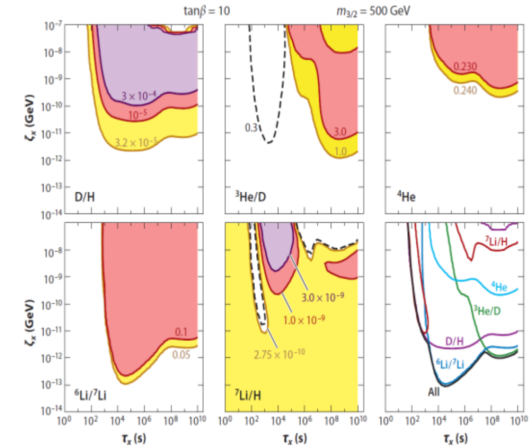
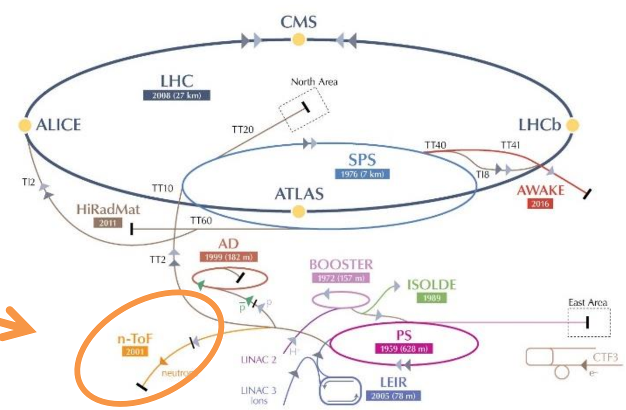


Neutron Time Of Flight facility: **n_TOF**



M. Barbagallo, *(n,cp) reactions study at the n_TOF facility at CERN: results for the Cosmological Lithium problem*, Varenna Conference 2018

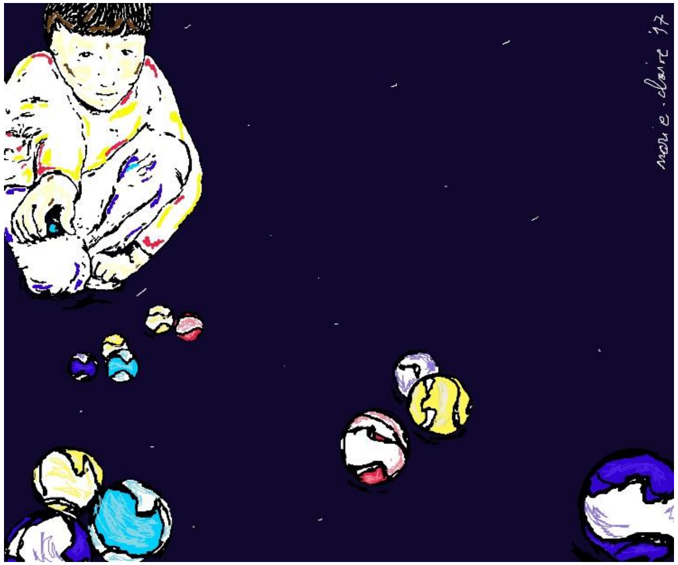

"Quand on était jeune.."

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.



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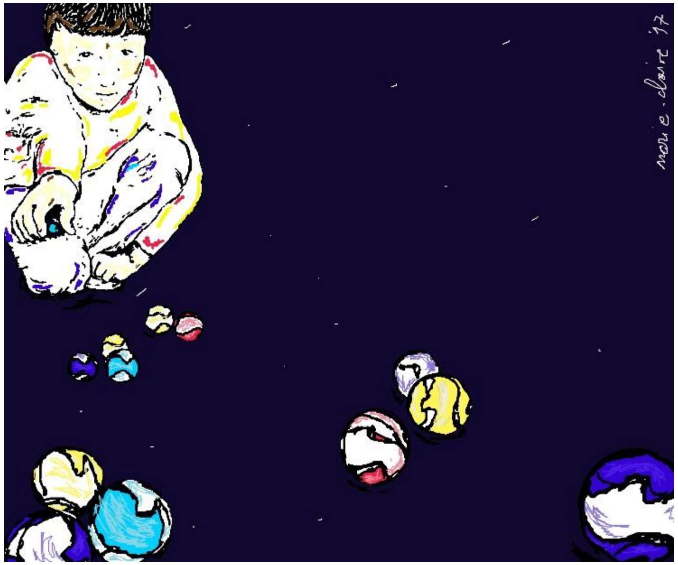
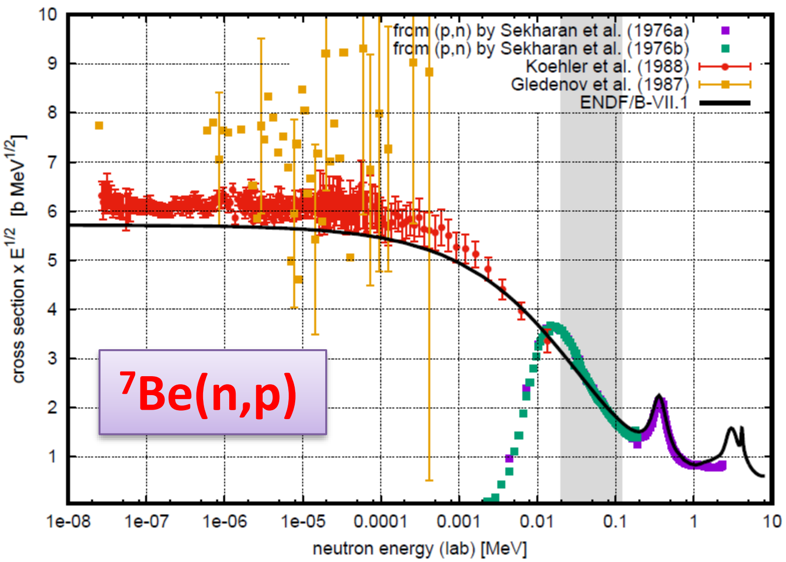
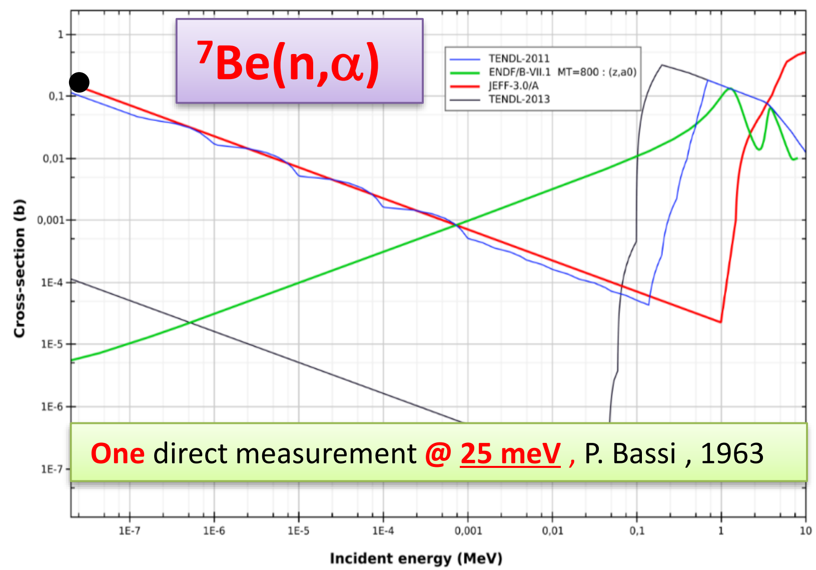
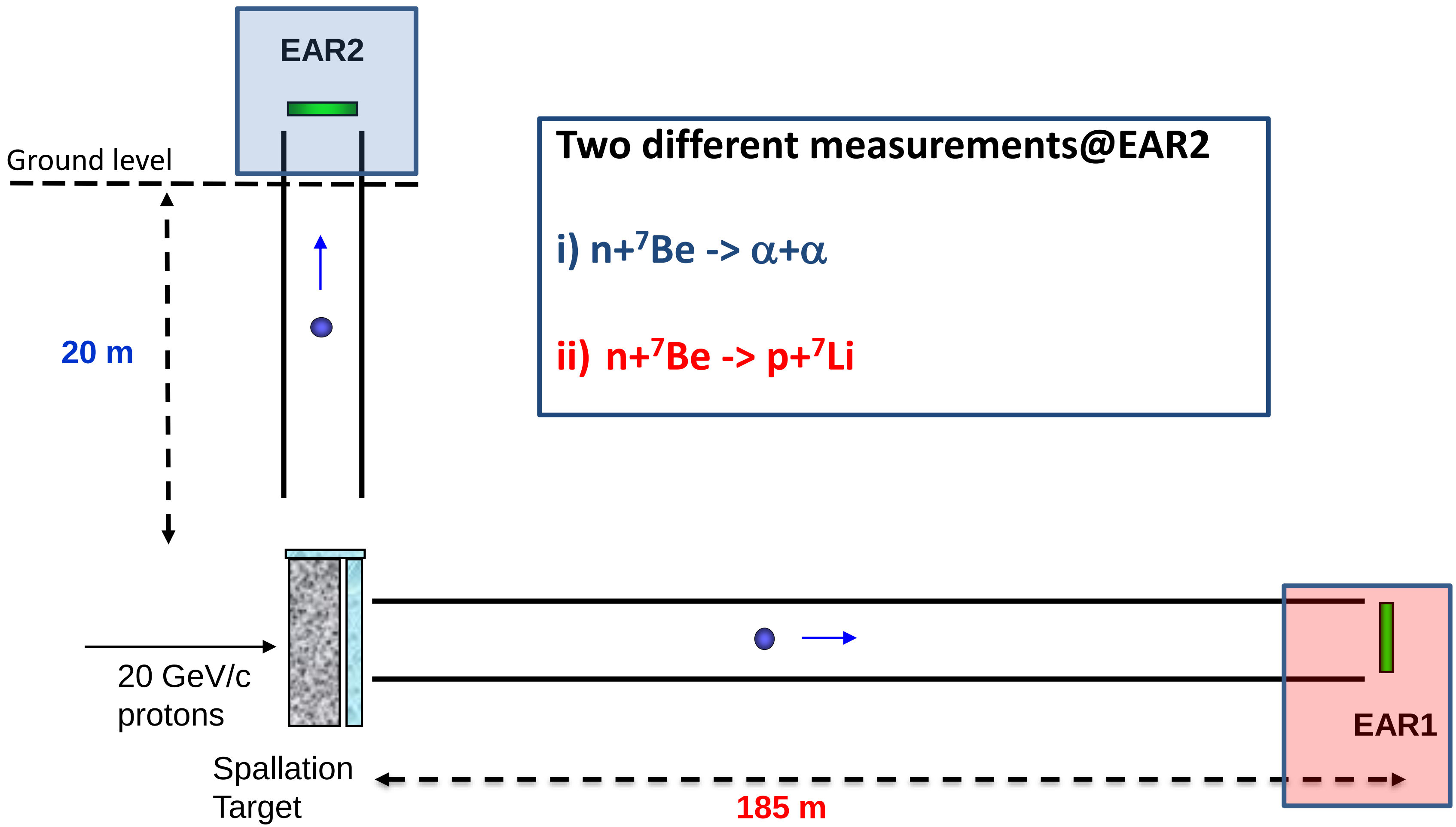






n_TOF program on CLiP

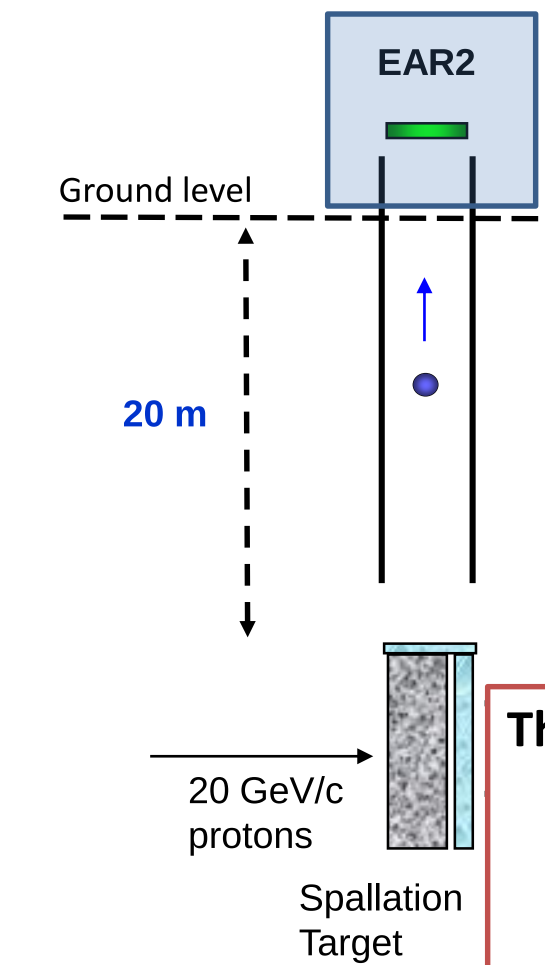


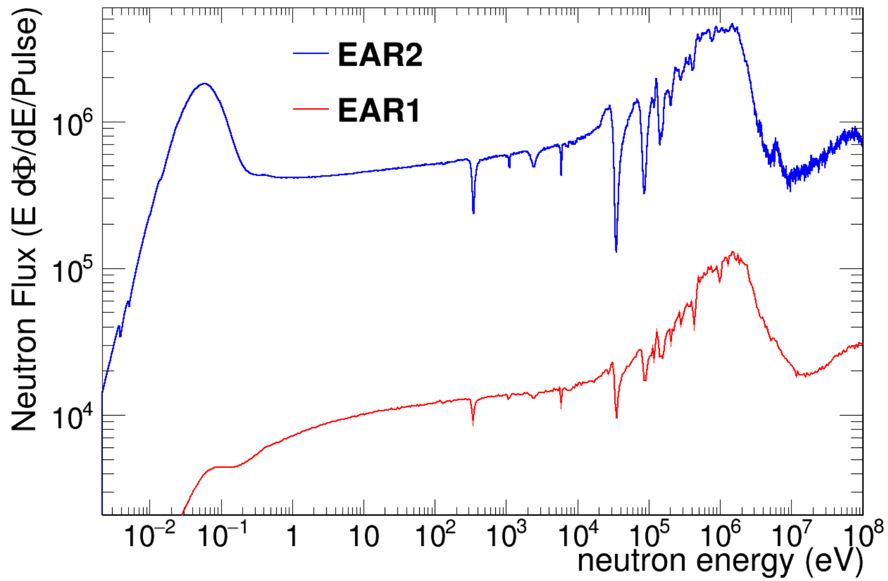
Two different measurements@EAR2

i) $n+^{7}Be \rightarrow \alpha+\alpha$

ii) $n+^{7}Be \rightarrow p+^{7}Li$

n_TOF program on CLiP





M. Barbagallo et al (n_TOF Coll.), Eur. Phys. J. A (2013) 49: 156
M. Sabate'-Gilarte et al (n_TOF Coll.), Eur. Phys. J. A (2017) 53: 210

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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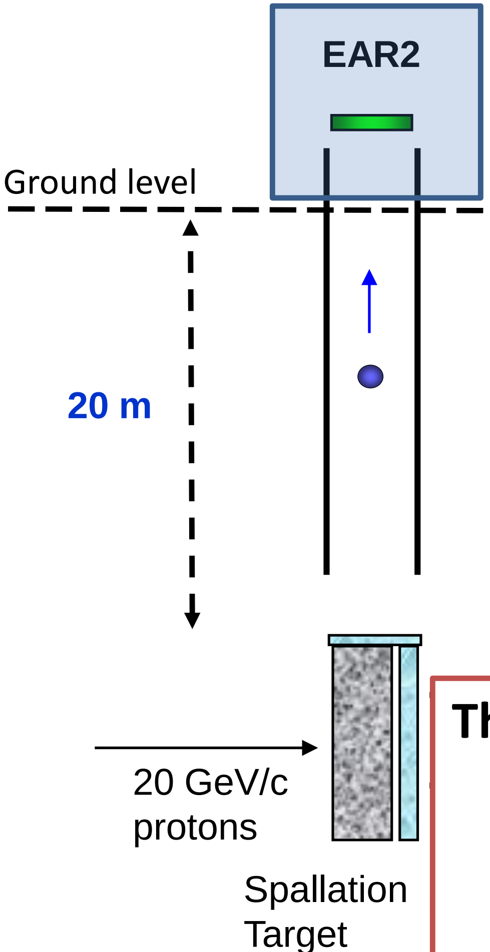

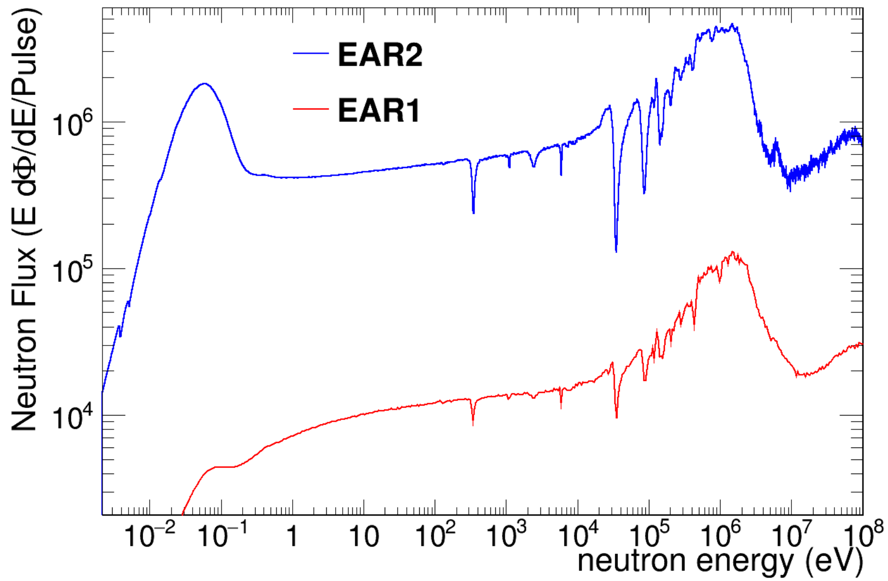

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Be-7

13 GBq/μg !!!

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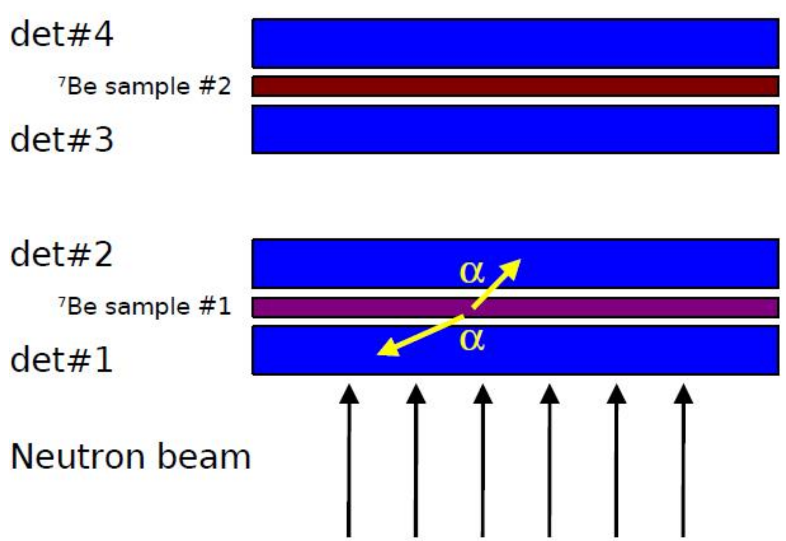
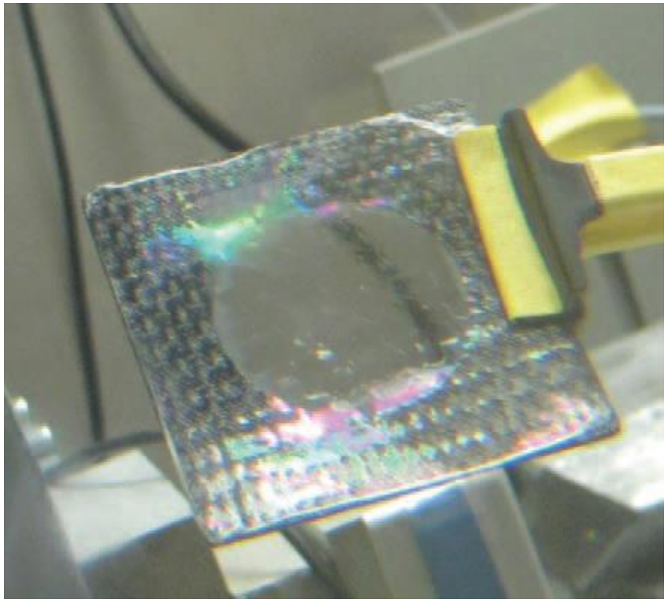
^{7}Be(n,$\gamma\alpha$)^{4}He measurement: the making of

n + ^{7}Be ----> ^{8}Be* ----> $\alpha + \alpha$ (+γ)   Q ~ 19 MeV

- Silicon detectors directly inserted in the beam
- Two different samples, 40 GBq total activity (prepared with different and independent techniques)



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

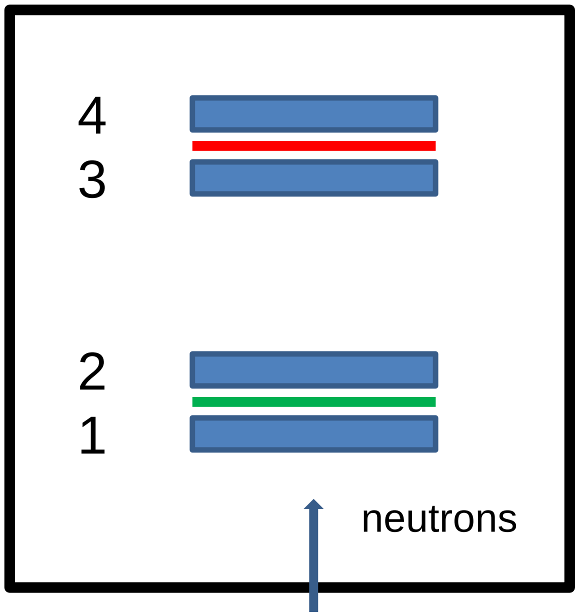


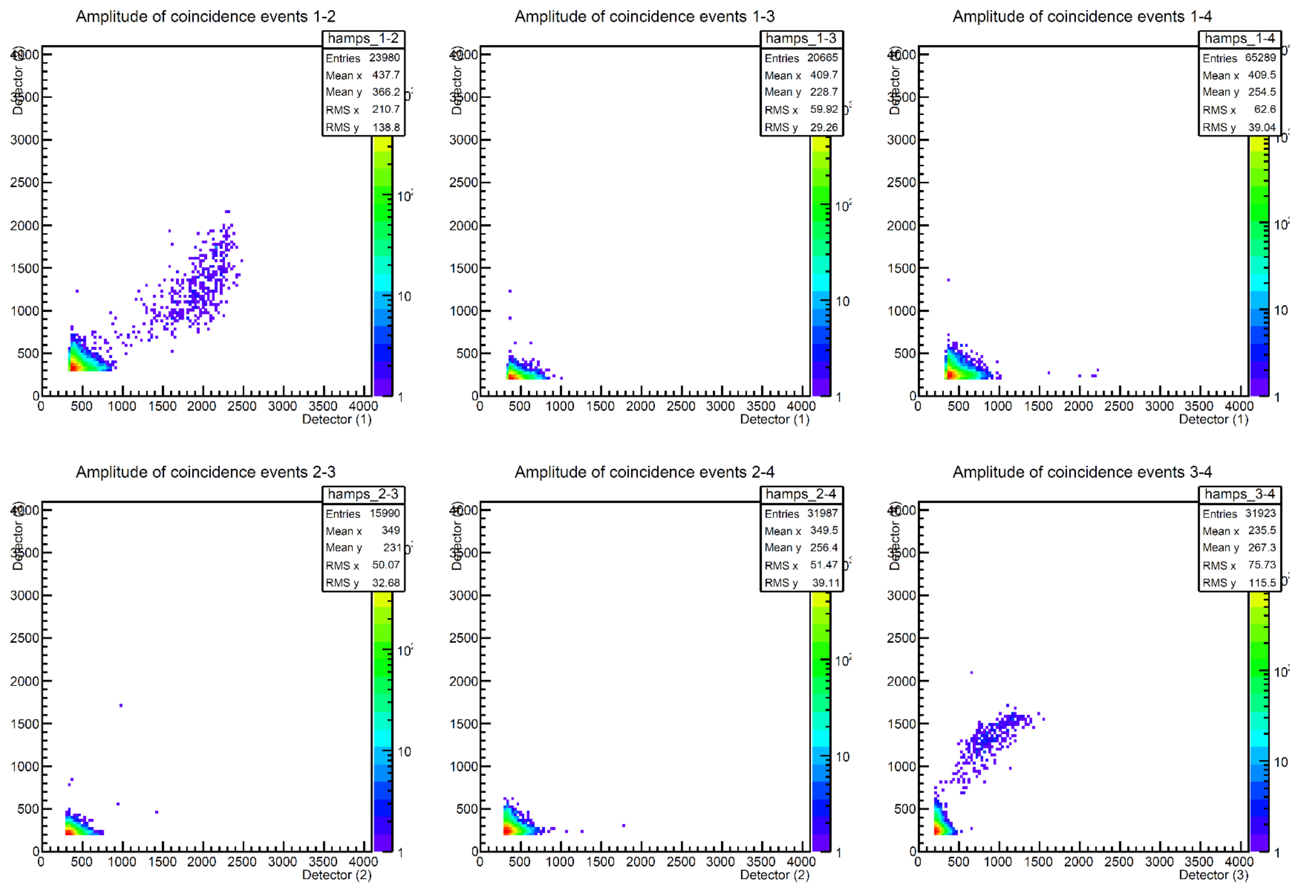
E. Maugeri et al. (n_TOF Coll.), Journ. of Instr., 12, P02016, (2017)

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

^{7}Be(n,$\gamma\alpha$) cross-section measurement

Two different sandwiches of silicon detectors.





Possible to evaluate random coincidences comparing uncorrelated couples of detectors.

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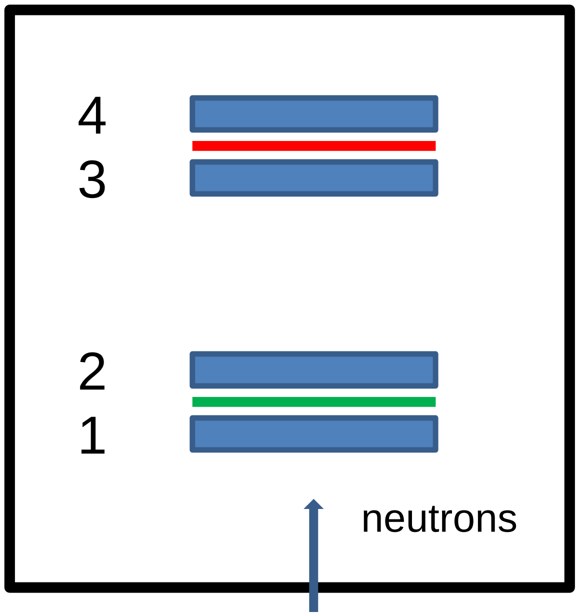

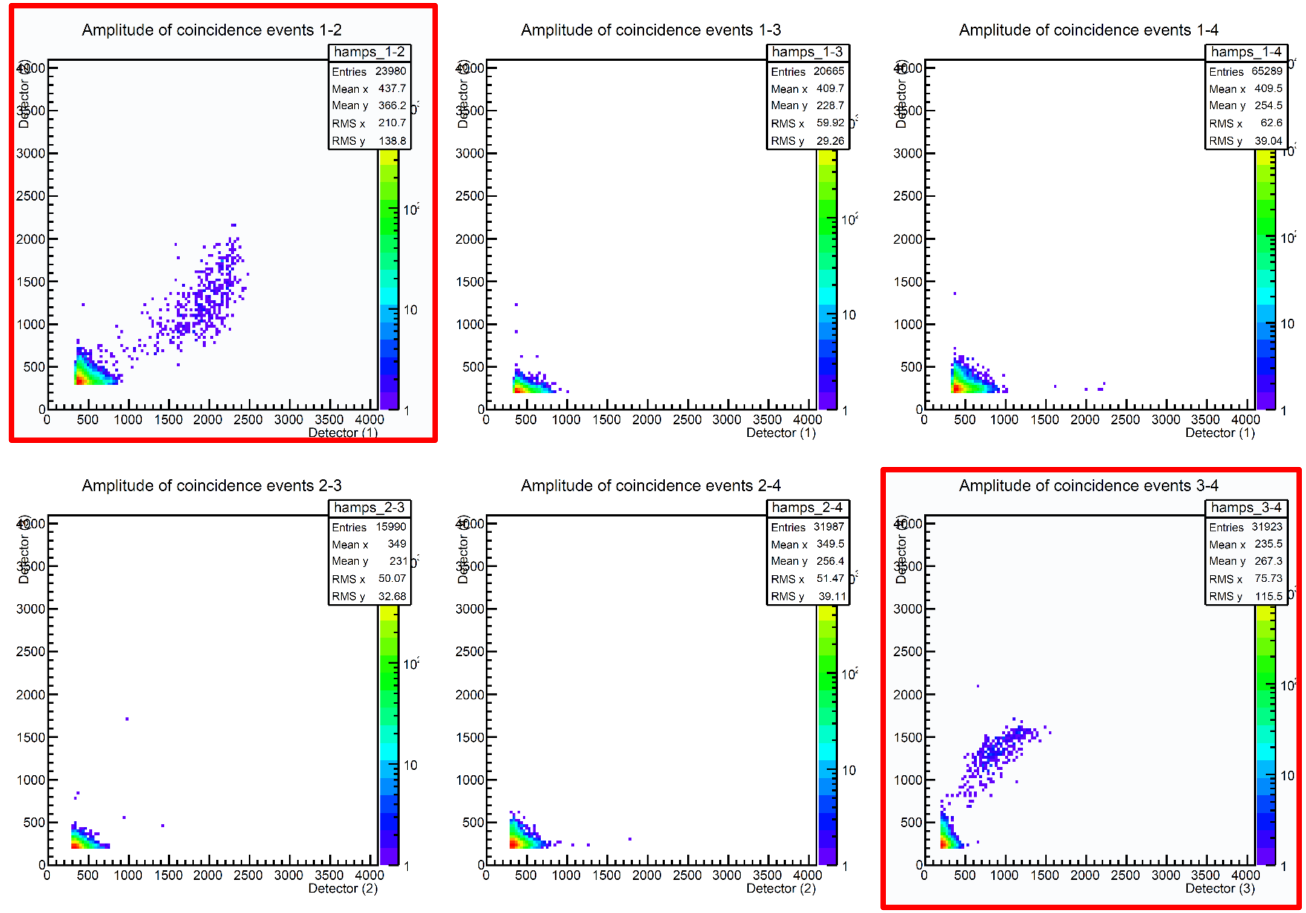

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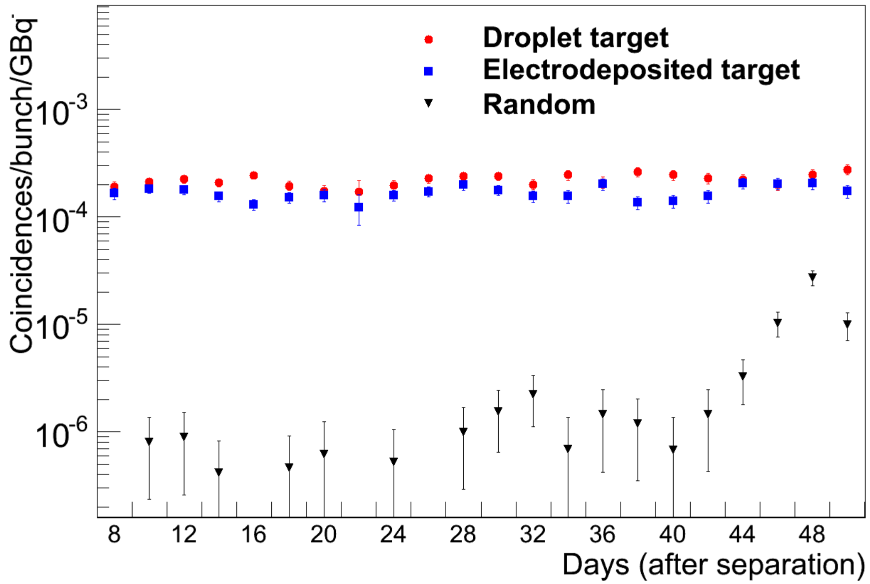
$^{7}Be(n,\gamma\alpha)^{4}He$ measurement: background rejection

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) $\longrightarrow \alpha+\alpha$
- $^{9}Be(n,2n)$, $^{7}Li(p,\gamma)$, $^{7}Be(p,\gamma)$

E_{dep}> 2 MeV



$^7Be(n,\gamma\alpha)^4He$ measurement: background rejection

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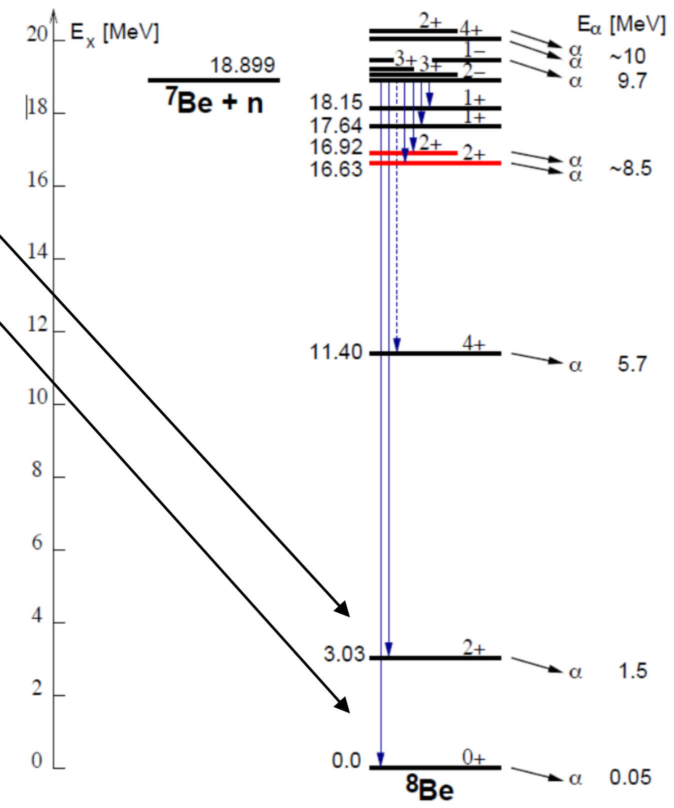
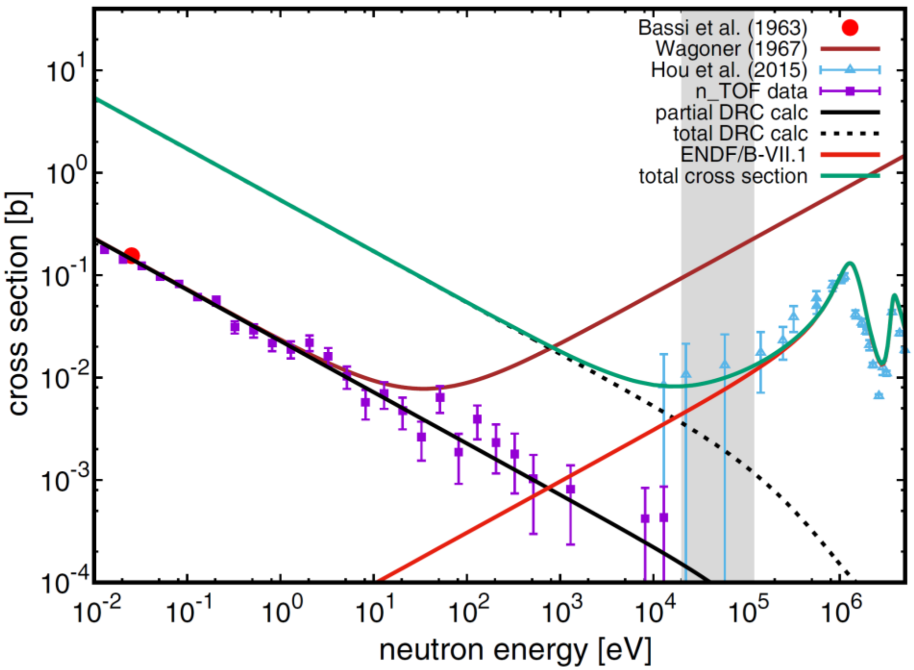
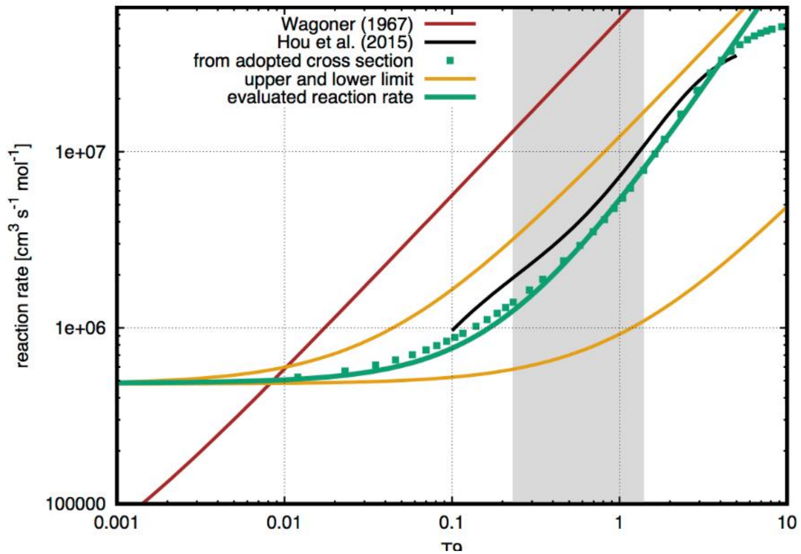
Two low energy states of ^8Be not accessible experimentally.

Missing states fractional contributions have been calculated.



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





$$N_A\langle\sigma v\rangle = 4.81\times10^5 + 1.84\times10^6 T_9 + 3.03\times10^6 T_9^{3/2}$$

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

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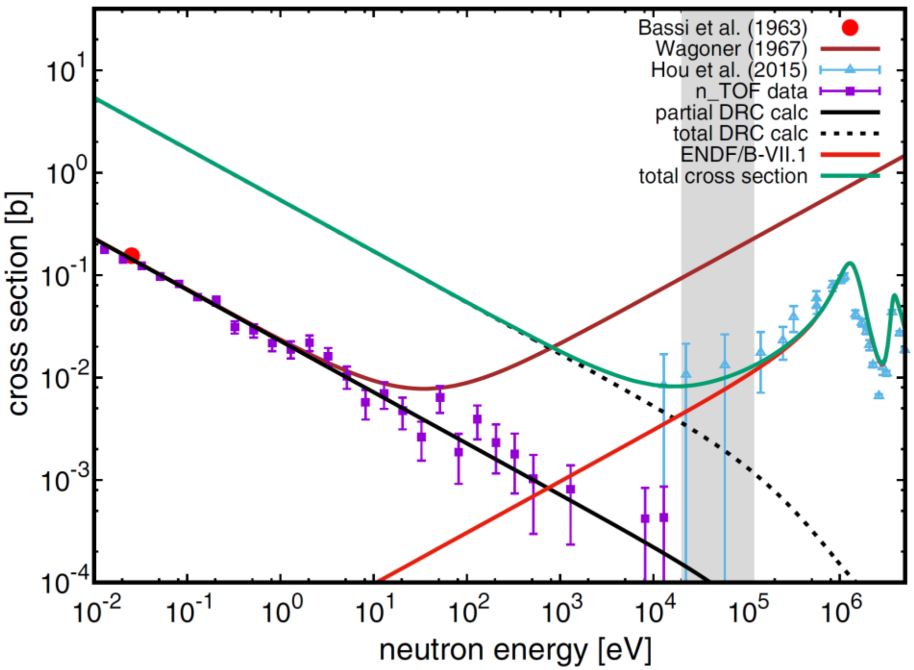

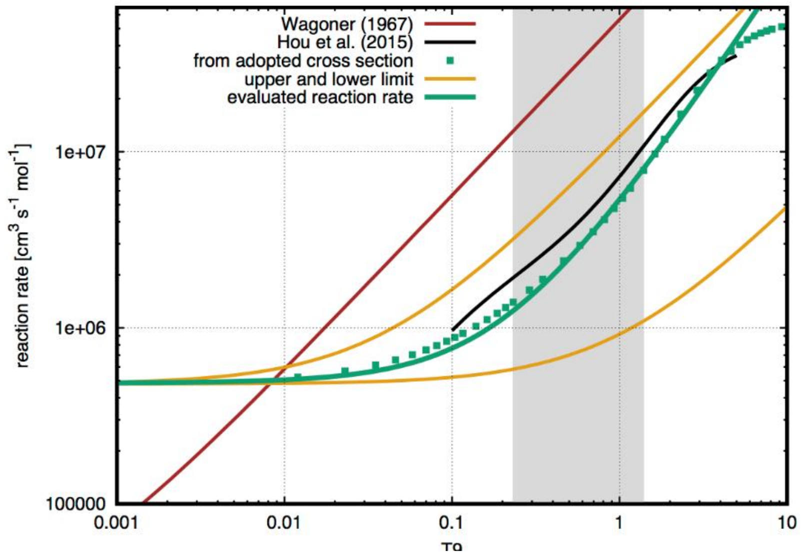

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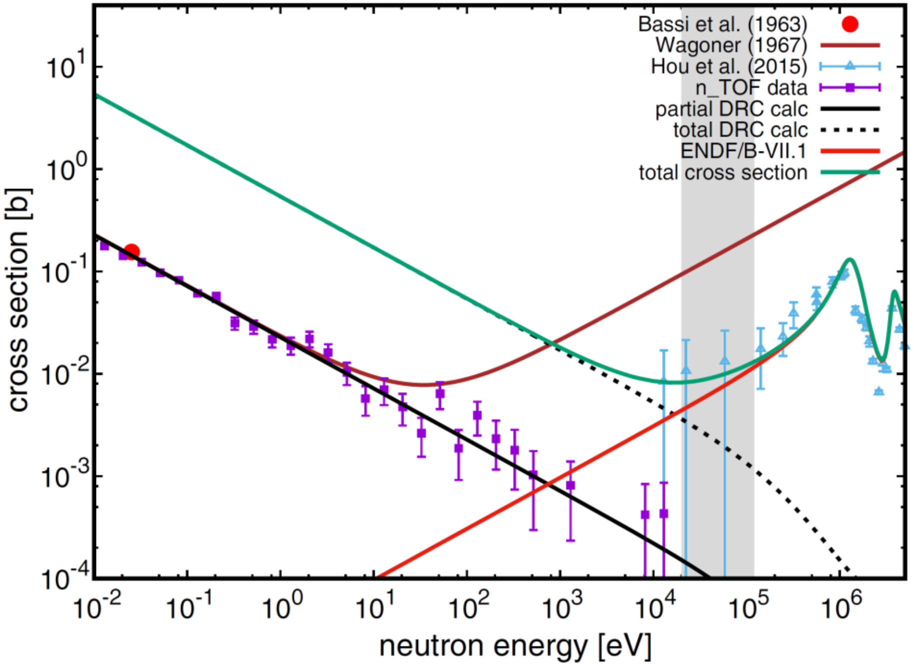
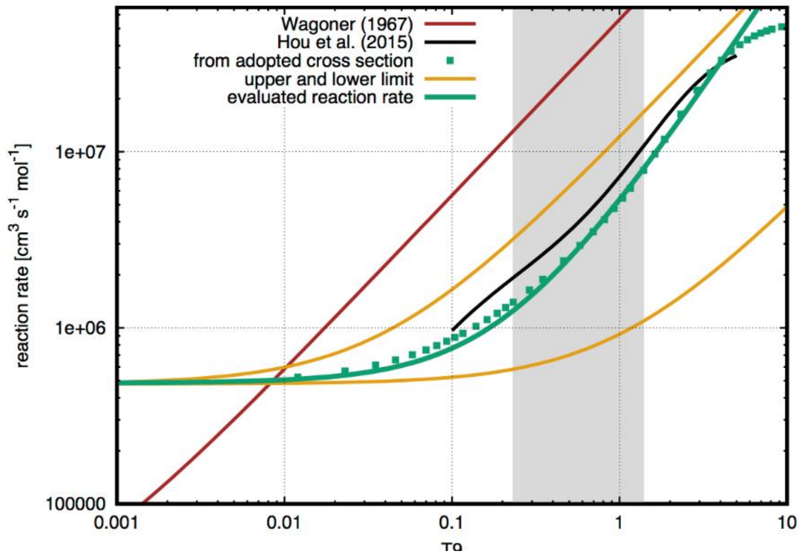
As for (n,α) measurement, the Cosmological Lithium Problem gets worse!





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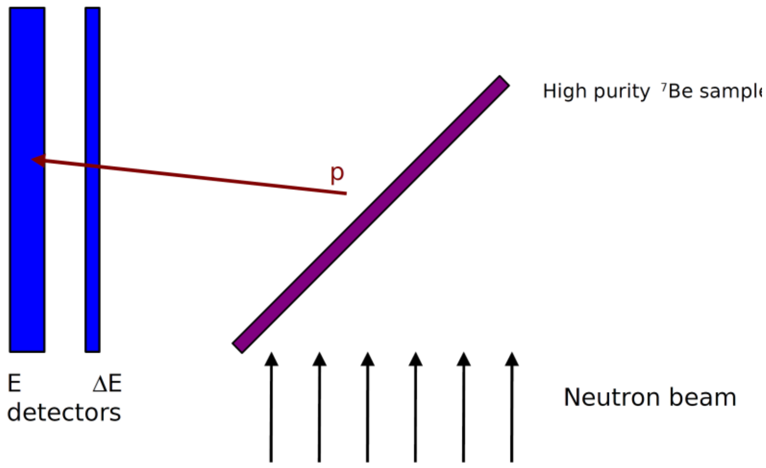
T. Kawabata et al., Phys. Rev. Lett. 118, 052701, 2017

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

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

Detection and identification of protons of 1.4 MeV and 1 MeV

Silicon telescope @n_TOF-EAR2.



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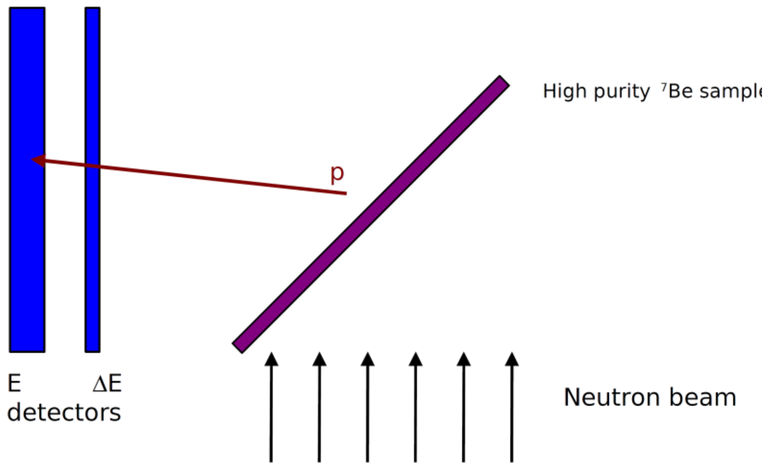

1 GBq high purity sample needed

(Chemical separation not sufficient)

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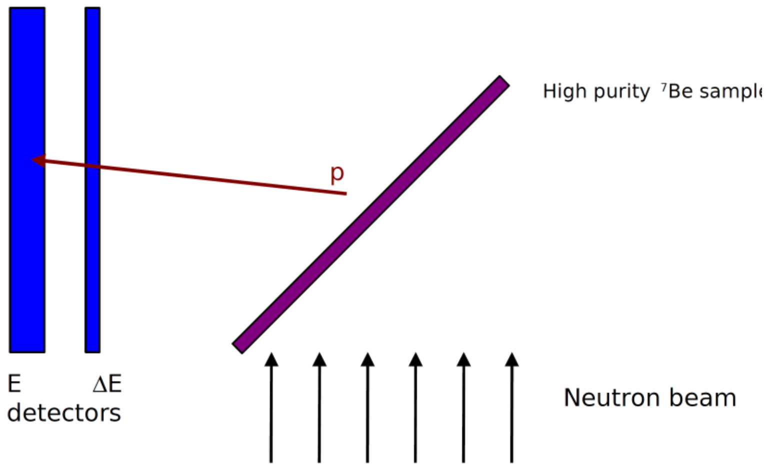

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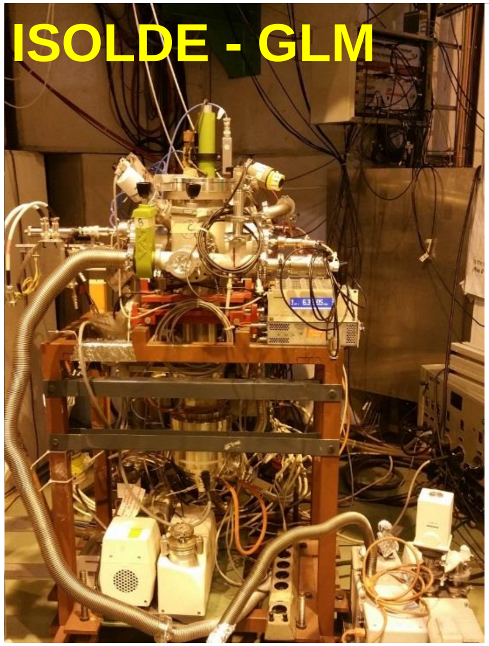
- **First joint n_TOF-ISOLDE experiment**
- **First time ever measurement of a neutron induced reaction cross-section using a target produced with a radioactive beam.**

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



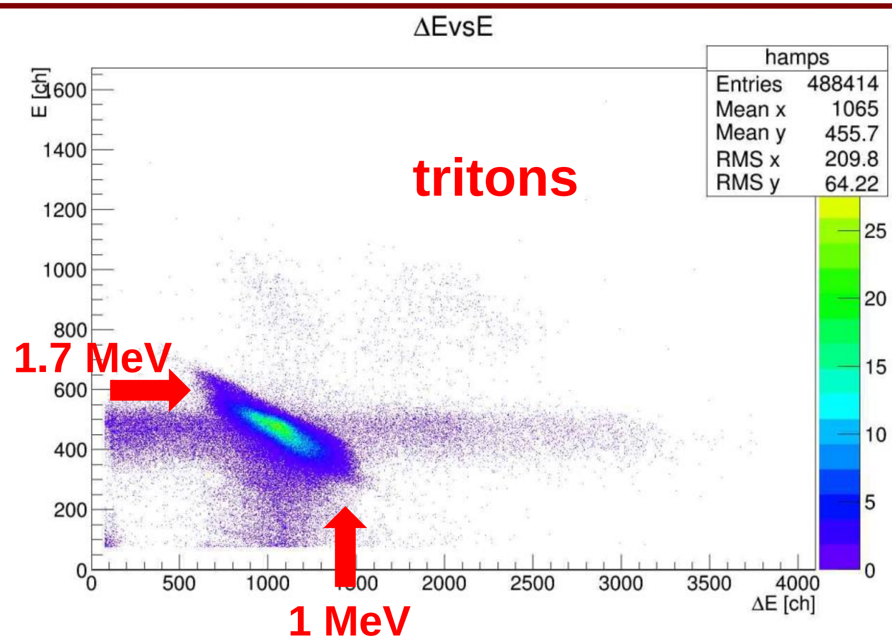
E. Maugeri et al., Nucl. Instr. and Meth. A 889 (2018) 138-144.
M. Barbagallo et al., Nucl. Instr. and Meth. A 887 (2018) 27-3

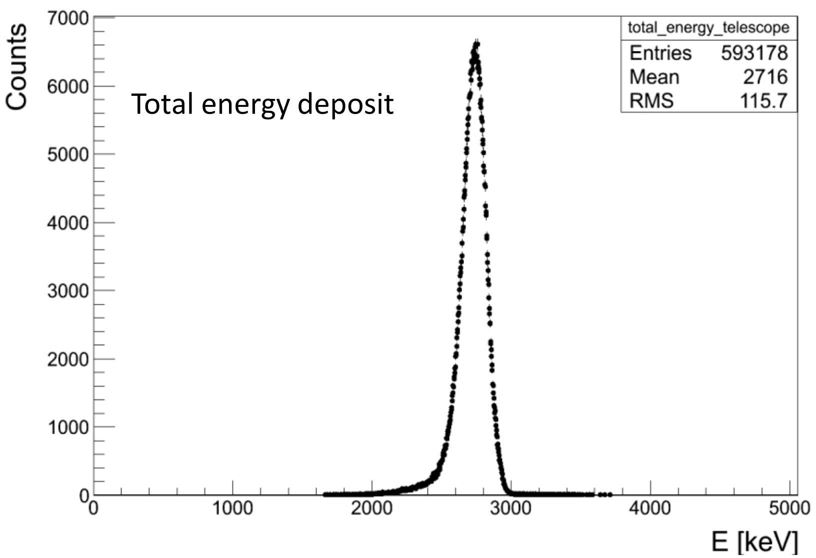
$^7Be(n,p)^7Li$ measurement

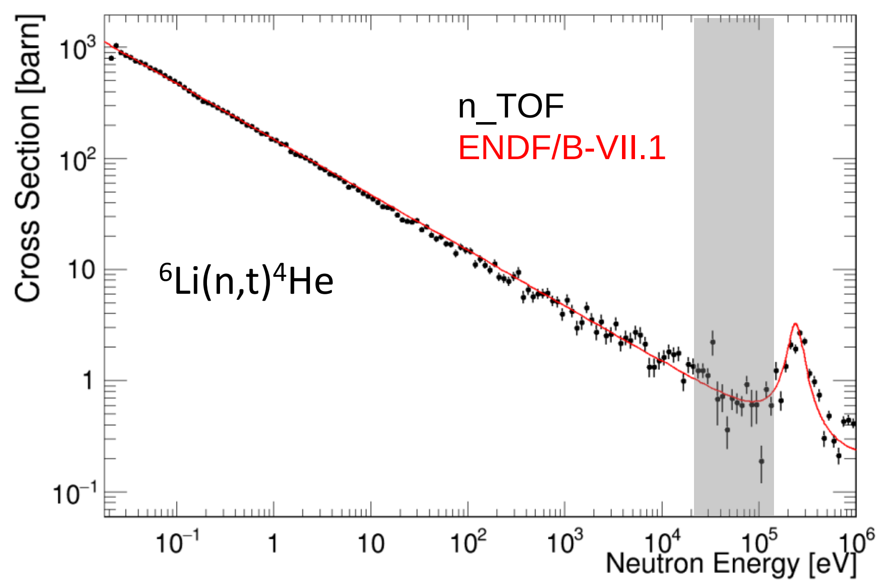
The detection system was characterized using α-source and the well-known $^6Li(n,t)^4He$ reaction.

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

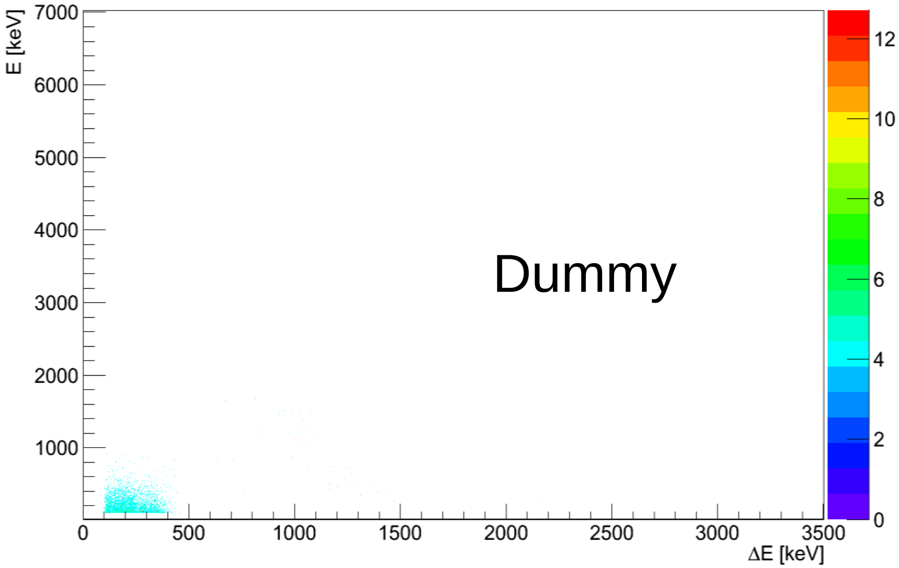
Q = 4.78 MeV

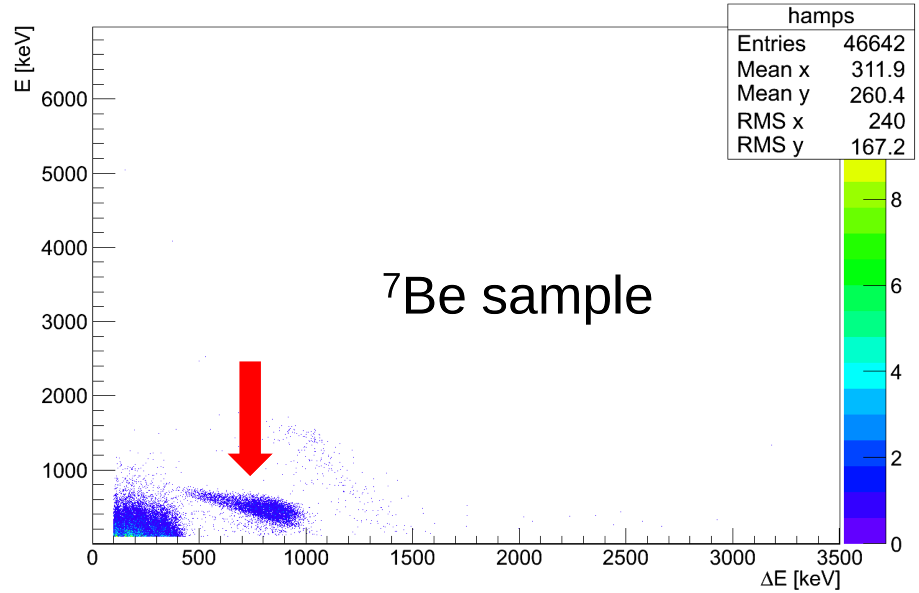


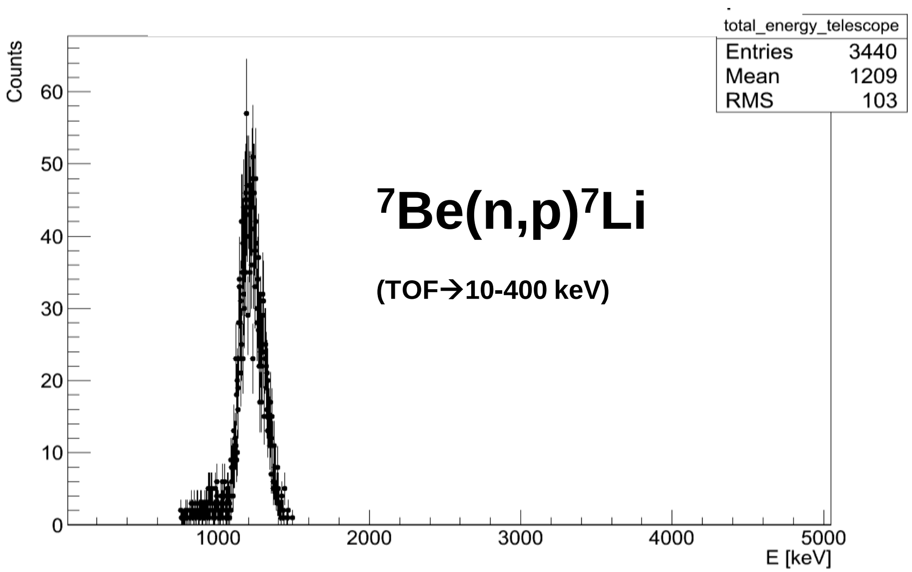




^{7}Be(n,p)^{7}Li measurement results



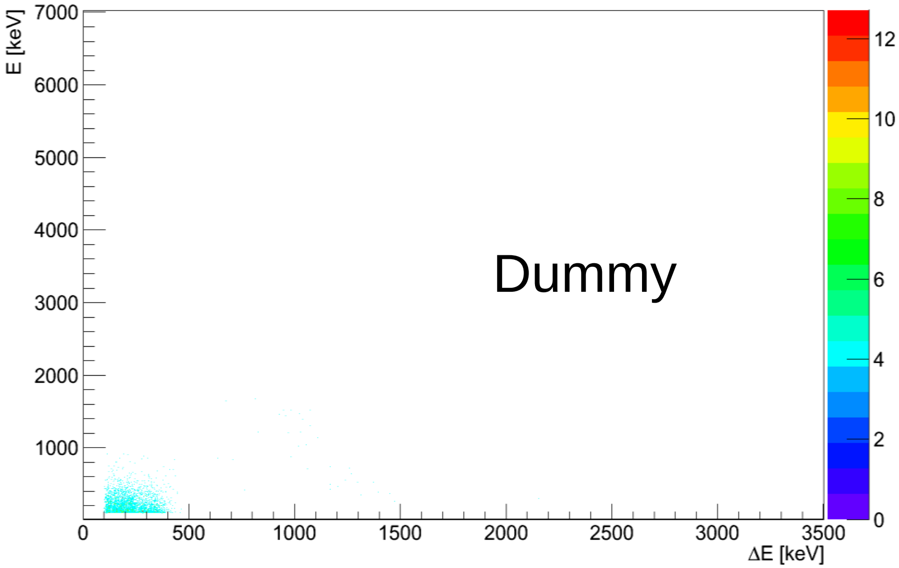


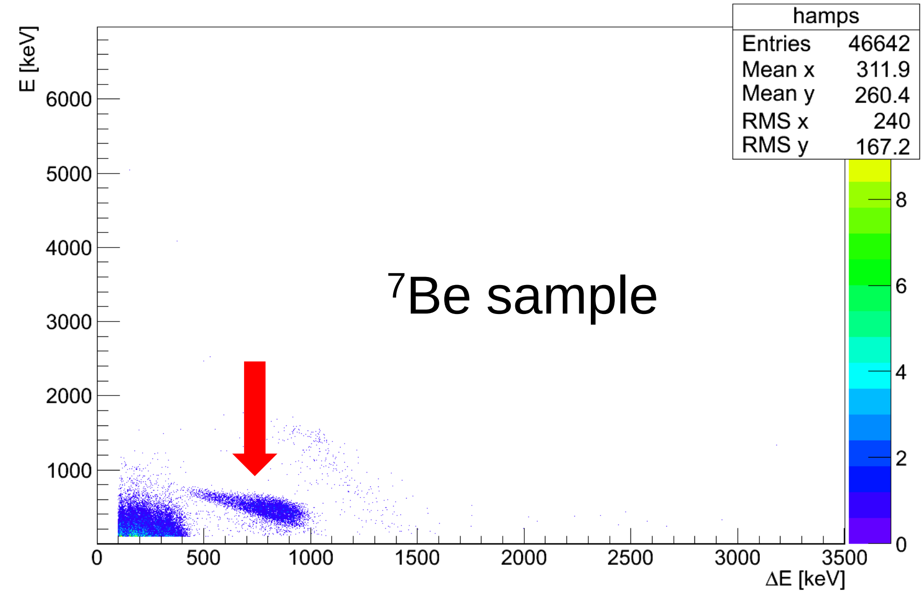


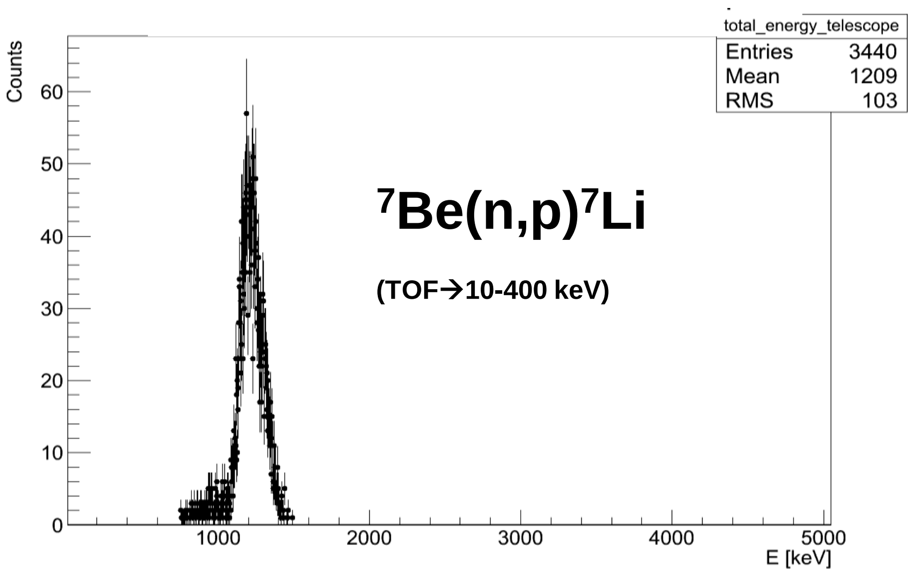
First time ever direct measurement of ^{7}Be(n,p) reaction in the range of interest for Big Bang Nucleosynthesis.

Stay tuned…

$^7Be(n,p)^7Li$ measurement results







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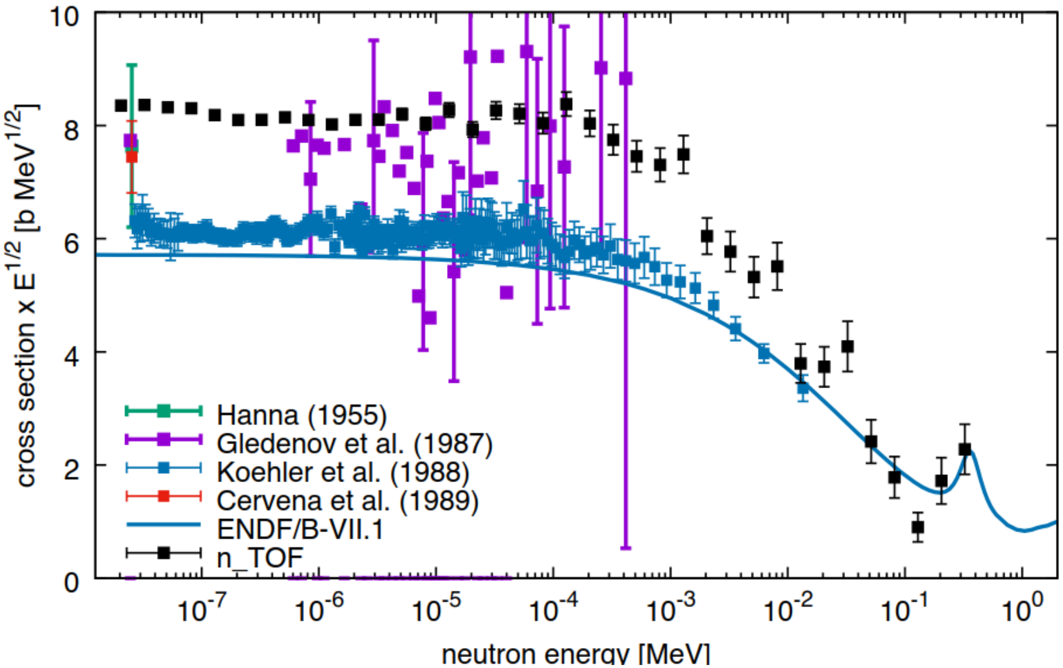

L. Damone et al. (n_TOF Coll.), submitted to Phys. Rev. Lett.

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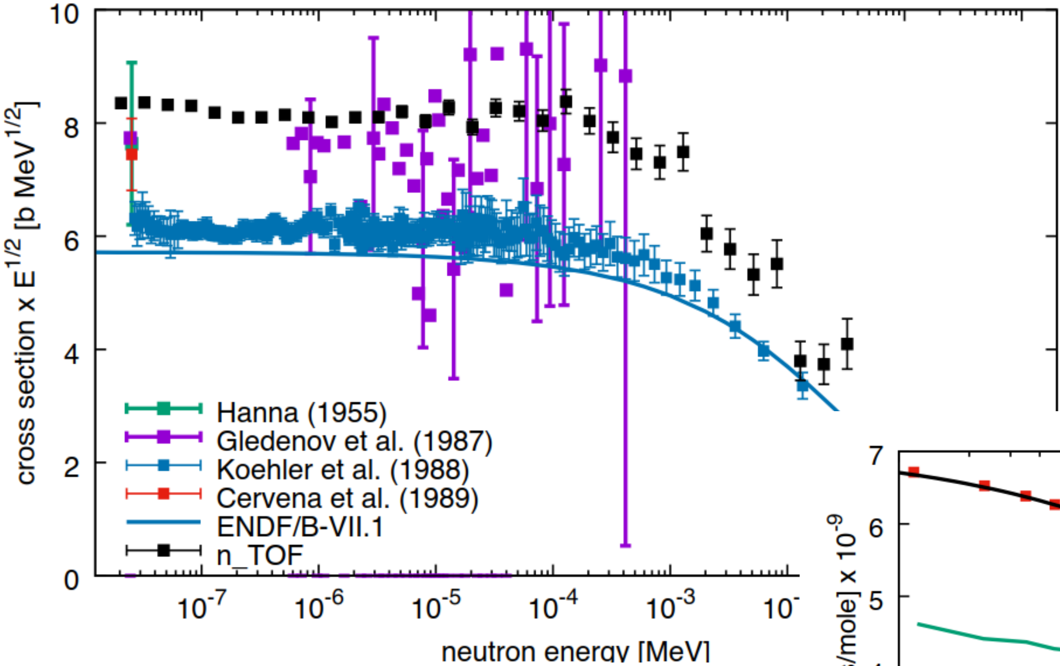

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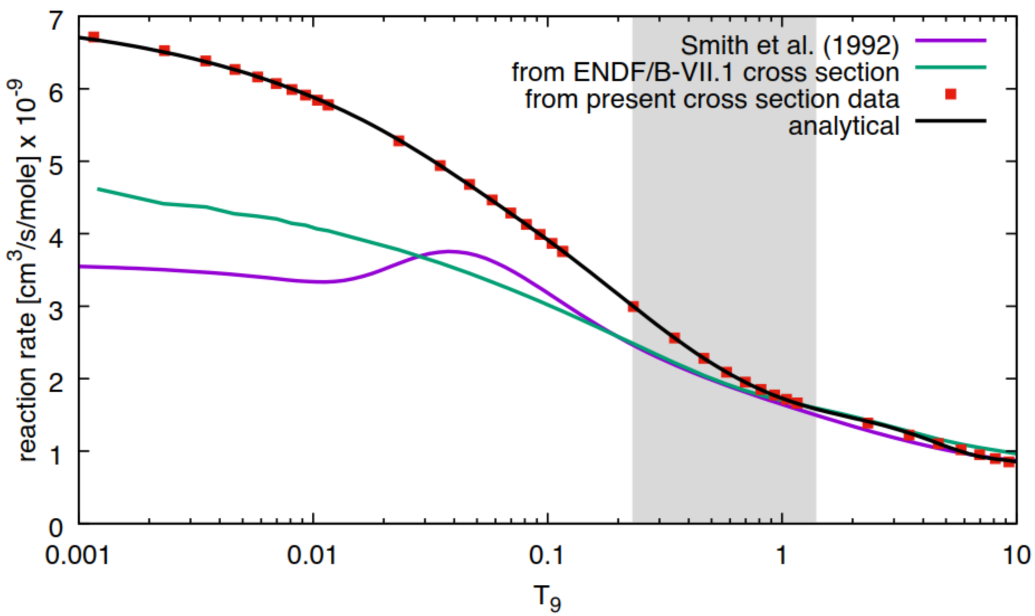

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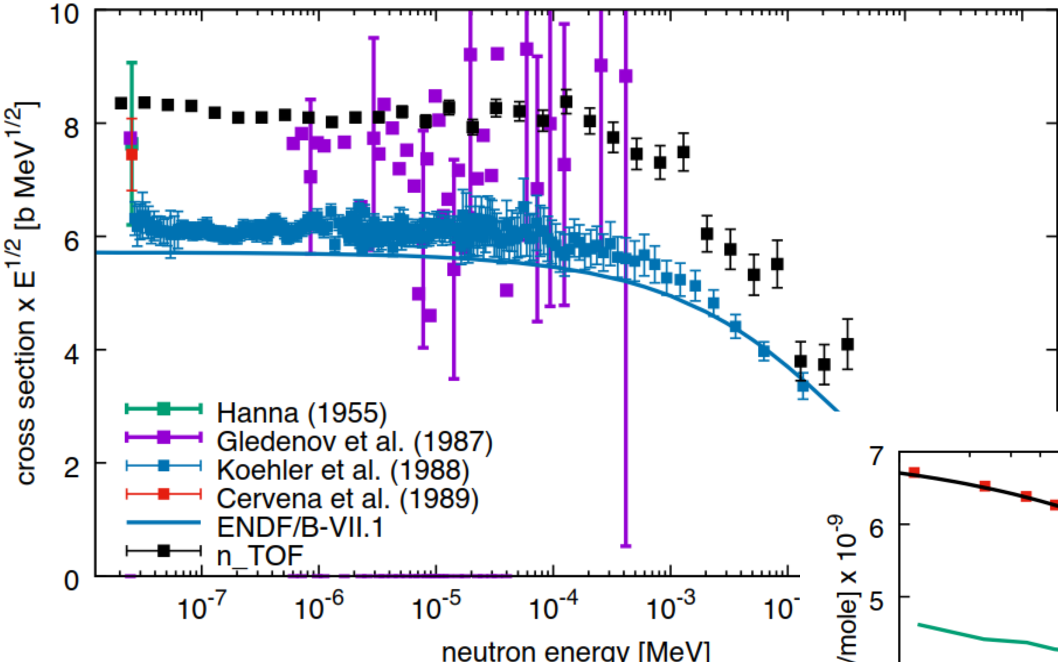
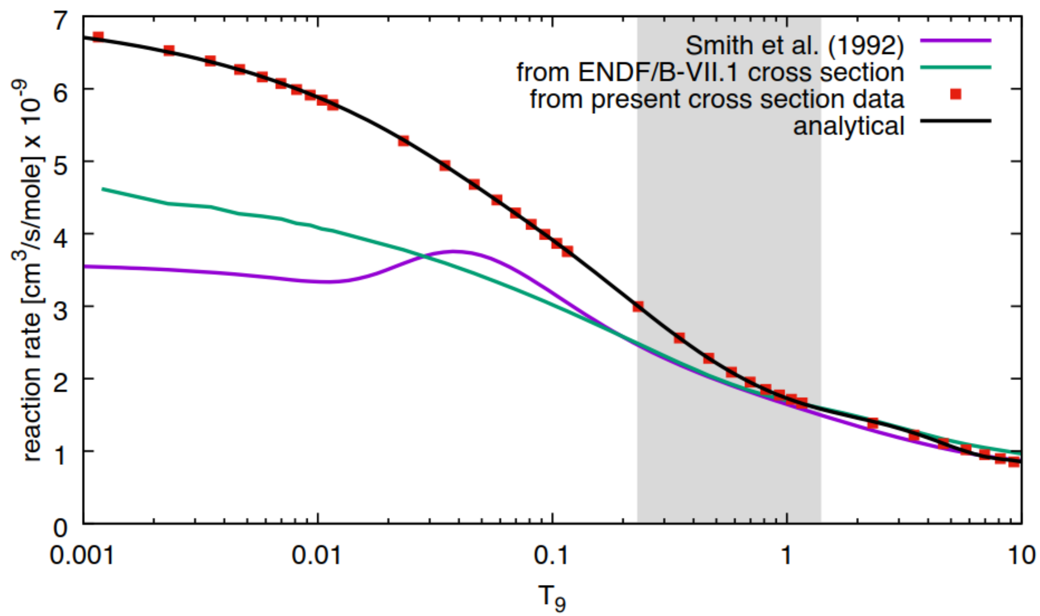


L. Damone et al. (n_TOF Coll.), submitted to Phys. Rev. Lett.



Solution to Cosmological Lithium Problem has to be sought in other Physics scenarios !!!

Conclusions

• 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 **^{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** from 0.02 eV to 500 keV **(first time at BBN energy window).**

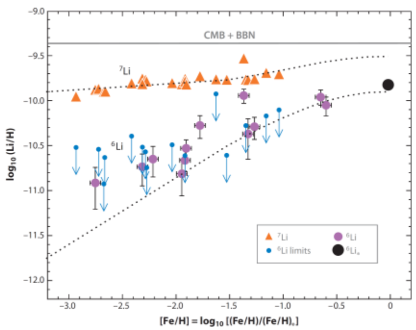
•The new estimate of the ^{7}Be destruction rate **based on the new n_TOF results** yields to a slight decrease of the predicted cosmological Lithium abundance, **insufficient to provide a viable solution to the Cosmological Lithium Problem.**

• **Solution to CLiP is somewhere else!**

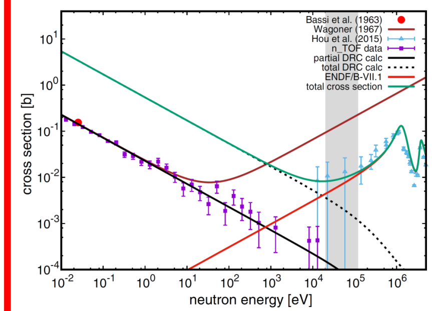
Perspectives

resonant states in 7Be(cp,X), lifetime in plasma..

Astrophysics model and observations

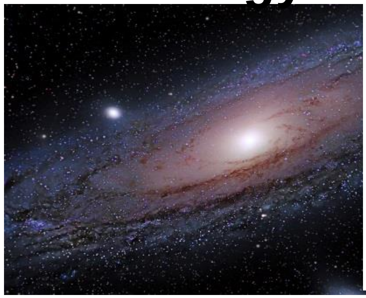


Nuclear Physics

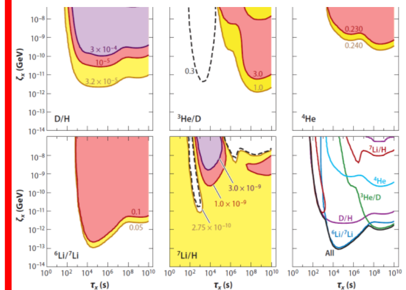


n_TOF

Non standard Cosmology



Physics beyond Standard Model



Log(Present knowledge) [a.u.]

Fascination [a.u.]

Conclusions

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• *The new data can be used for more accurate calculation of the reaction yield and neutron spectrum in the near-threshold ^{7}Li(p,n)^{7}Be reaction, important for neutron sources and Nuclear Astrophysics.*

Implication on ^{7}Li(p,n) based neutron sources

The **present data** can also provide information on cross-section of the ^{7}Li(p,n)^{7}Be reaction, one of the most important reactions for **neutron production at low-energy accelerators.**

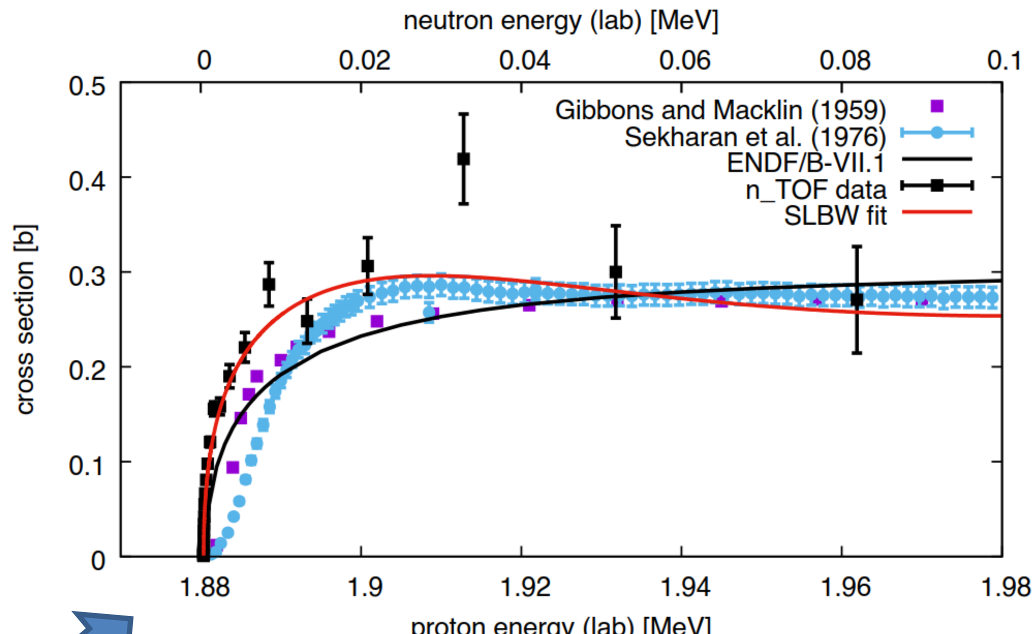
Need to know **excitation function** for ^{7}Li(p,n)^{7}Be reaction **@25-30 keV**

- low energy of emitted neutrons
- well calibrated stable proton beam
- poor energy resolution

BUT..

^{7}Li(p,n)^{7}Be ⟷ ^{7}Be(n,p)^{7}Li

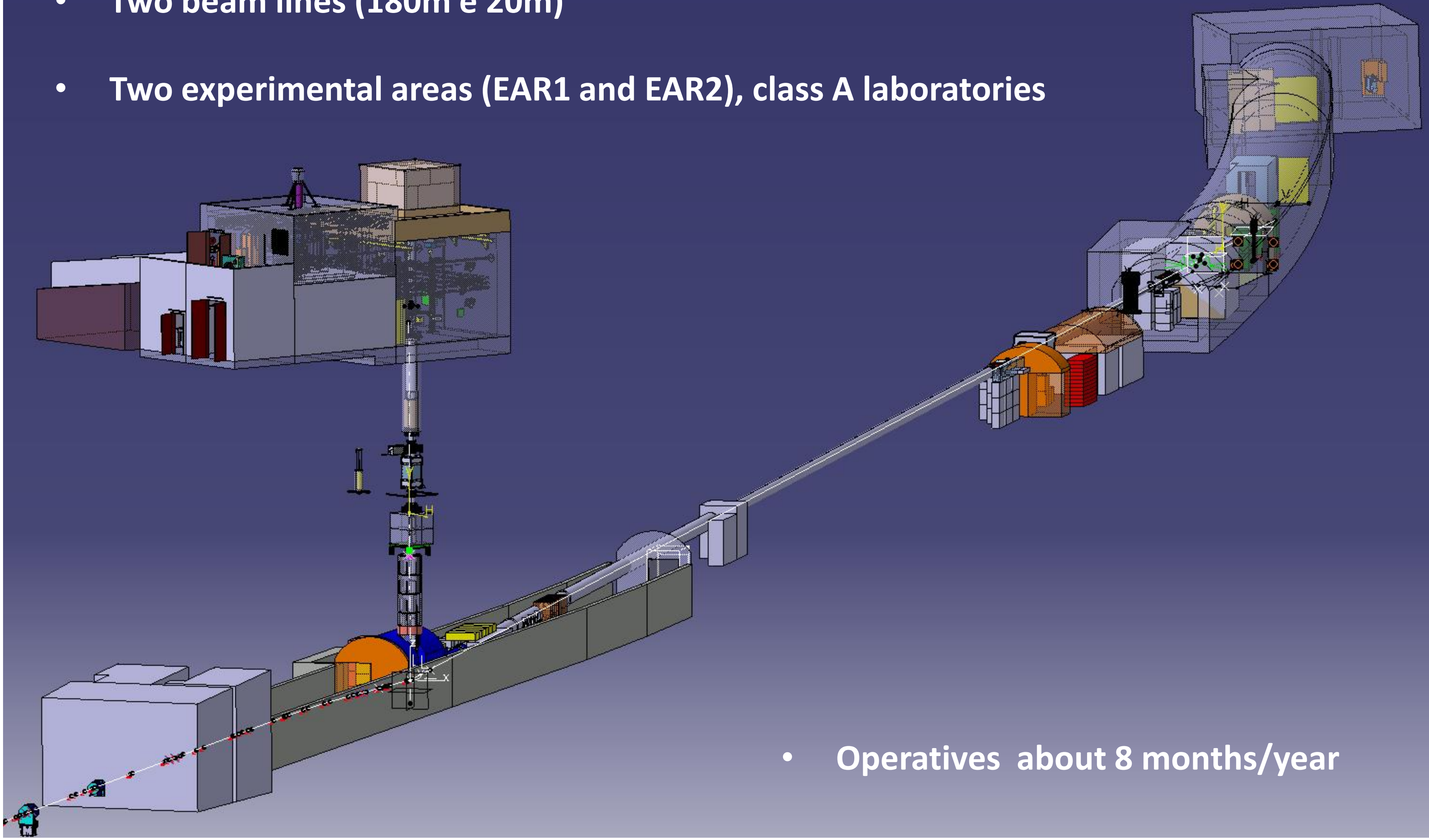
n_TOF



Compared with direct measurements, the extracted excitation function shows a much faster rise above the threshold.

The n_TOF facility at CERN

- Two beam lines (180m e 20m)
- Two experimental areas (EAR1 and EAR2), class A laboratories



- Operatives about 8 months/year

n_TOF Features

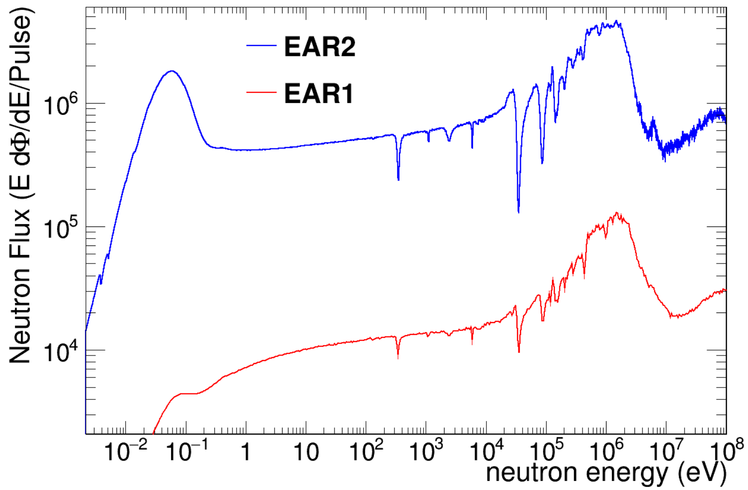
Advantages of the **Proton Synchrotron beam**: **high energy, high peak current (7e12 ppp/7 ns)**

High instantaneous neutron flux

(10^5 n/cm^2/pulse and 10^7 n/cm^2/pulse).

Very convenient for measurements of:

- radioactive isotopes,
- low cross sections,
- isotopes available in small quantities



Other features of the neutron beams:

- High **resolution in energy** *($\Delta E/E = 10^{-4}$ in EAR1 and $\Delta E/E = 10^{-3}$ in EAR2)*
- Wide **energy range** *(1 meV$<E_n<$1 GeV)*
- Low **repetition** rate(*< 0.8 Hz*) *(no wrap-around)*