# Measurement of the $^{7}\mathrm{Be(n,p)}\,^{7}\mathrm{Li}$ cross section in EAR2@n_TOF for the Cosmological Lithium Problem

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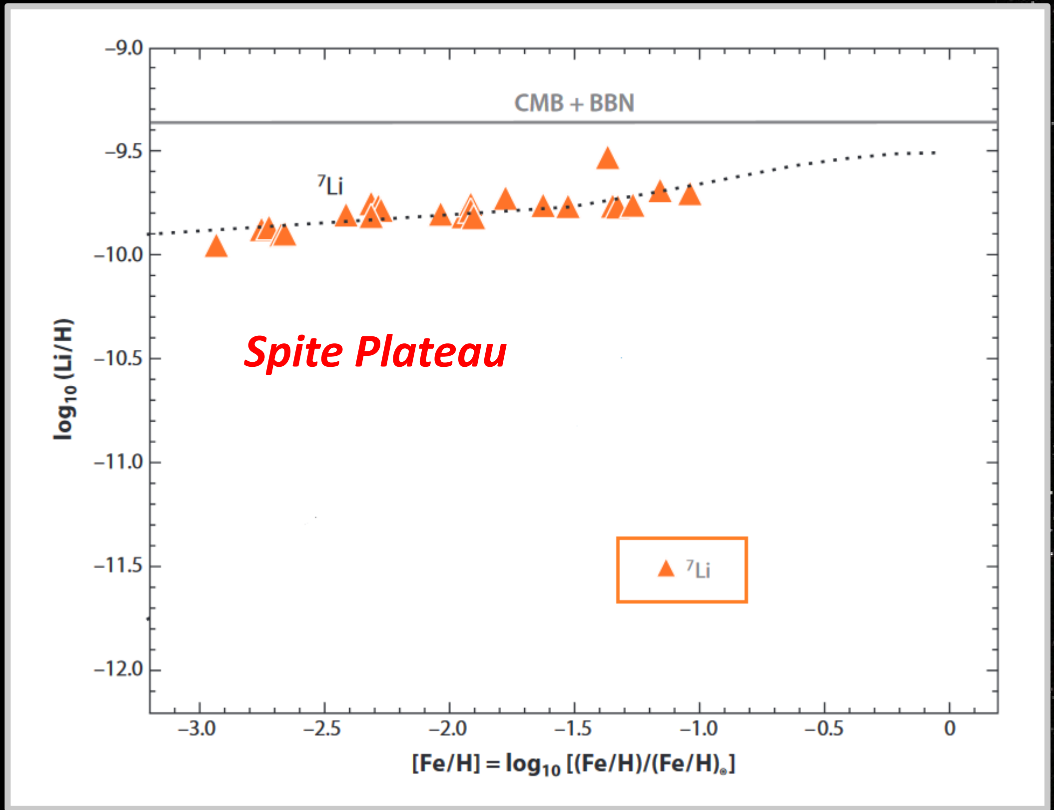
# Outlook

- The Cosmological Lithium Problem
- Experimental Set-up for the $^{7}\mathrm{Be(n,p)}$ cross-section
- Geant4 Simulations
- Preliminary results for the $^{7}\mathrm{Be(n,p)}$ measurement
- Conclusions

# The Cosmological Lithium Problem

*Discrepancy of a factor 2-3 between observations and Theoretical predictions of the $^{7}Li$ abundance!*

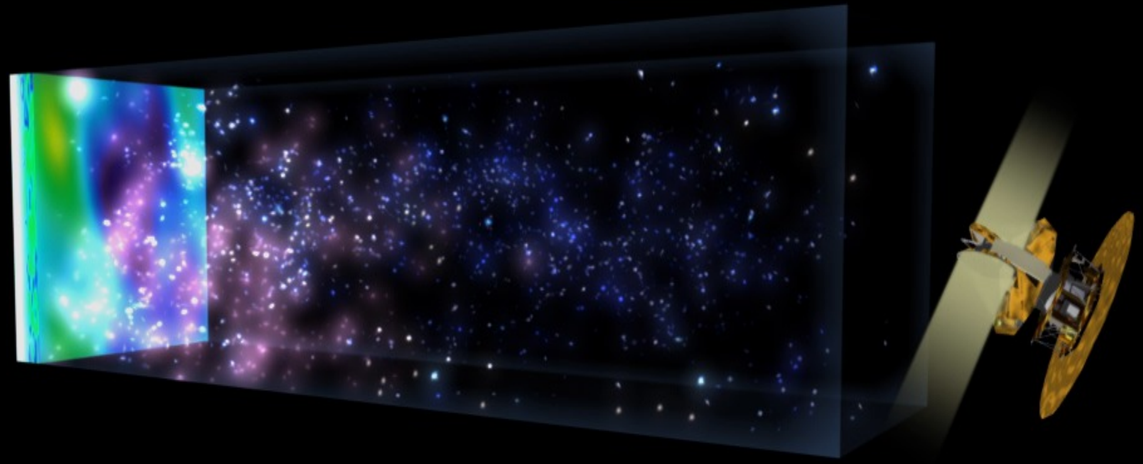
# The Cosmological Lithium Problem Observations




$$\left(\frac{Li}{H}\right)_{obs} \cong (1.7 \pm 0.06 \pm 0.44) \times 10^{-10}$$

# The Cosmological Lithium Problem
# Theoretical predictions

WMAP : $\left(\frac{Li}{H}\right)_{BBN} \cong (5.12^{+0.71}_{-0.62}) \times 10^{-10}$



$$\eta \equiv \frac{N_b}{N_\gamma} = 2.74 \times 10^{-8}\Omega_b h^2$$

# The Cosmological Lithium Problem

## *Nuclear solutions*

According to the Big Bang Nucleosynthesis the **95%** of the primordial $^{7}\mathrm{Li}$ comes from electronic capture decay of the $^{7}\mathrm{Be}$

$$^{7}Be \quad + \quad e^{-} \quad = \quad {}^{7}\mathrm{Li} \quad + \quad \nu_e$$

A higher rate of $^{7}\mathrm{Be}$ destruction could solve or, at least, partially explain the probem.

# The Cosmological Lithium Problem

***Possible $^{7}Be$ destruction channels***

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$^{7}Be + d$

$^{7}Be + t$

$^{7}Be + \,^{3}He$

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*Considerable effect just if new unknown resonances are found*

# The Cosmological Lithium Problem

*Sub-dominant destruction channels involving charged nuclei*

$^{7}Be + d$ → *Maximum achievable effect: 40% reduction of primordial $^{7}Li$*

$$E_r \sim 150\ keV,\ \Gamma_{tot}(E_r, R) \sim 45\ keV$$

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## One fewer solution to the cosmological lithium problem

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A recent theoretical paper [7] explores the possibility of enhancing $^{7}Be$ destruction through resonant reactions with $p$, $d$, $t$, $^{3}He$, and $\alpha$, leading to compound states in $^{8}B$, $^{9}B$, $^{10}B$, $^{10}C$, and $^{11}C$, respectively. The paper concludes that, of the known excited states in these isotopes [8,9], only the 16.8-MeV state in $^{9}B$ has the potential to significantly influence $^{7}Be$ destruction.[2] (Note that in Ref. [7] this state is referred to as the 16.7 MeV state.) The proposed destruction mechanism is shown schematically in Fig. 1. The 16.8-MeV state in $^{9}B$ is formed by the fusion of $^{7}Be$ with a deuteron and decays by proton emission to a highly excited state in $^{8}Be$, 16.626 MeV above the ground state, which subsequently breaks up into two $\alpha$ particles. (The last step is not shown in the figure.) The reason why the decay must proceed by proton emission to the 16.626-MeV state in $^{8}Be$ and not, for example, the ground state is explained later.

The reaction rate depends critically on the resonance energy, $E_r$ (i.e., the energy of the 16.8-MeV state relative to the $d + {}^{7}Be$ threshold at $S_d = 16.4901(10)$ MeV [8]): if too far above the threshold, the tunneling process will be too slow at BBN temperatures. Furthermore, for the proposed destruction mechanism to be efficient, the 16.8-MeV state must have an appreciable width, $\Gamma_d$, for being formed in the $d + {}^{7}Be$ channel, but also an appreciable width, $\Gamma - \Gamma_d$, for not decaying back to $d + {}^{7}Be$. The energetically allowed decay modes competing with deuteron emission are $\gamma$, $p$, $\alpha$, and $^{3}He$. However, $\gamma$ and $^{3}He$ can safely be neglected. A deuteron width, $\Gamma_d$, of the required magnitude can only be realized if the 16.8-MeV state is not too close to the threshold. The analysis of Ref. [7] shows that the cosmological lithium problem can be resolved provided $E_r \simeq 170$–$220$ keV, $\Gamma_d \simeq 10$–$40$ keV, and $\Gamma - \Gamma_d \simeq \Gamma_d$. At the time Ref. [7] was written, the known properties of the 16.8-MeV state did not contradict these requirements: The 16.8-MeV state had been observed in two experiments [11,12]. Its energy was determined to be 16.7 MeV with an uncertainty of 100 keV, and only an upper limit of 100 keV existed on its total width. Its spin and parity were not determined, though a tentative $5/2^{+}$ assignment was made [13] based on comparison to the mirror nucleus, $^{9}Be$. No information existed on its decay properties.

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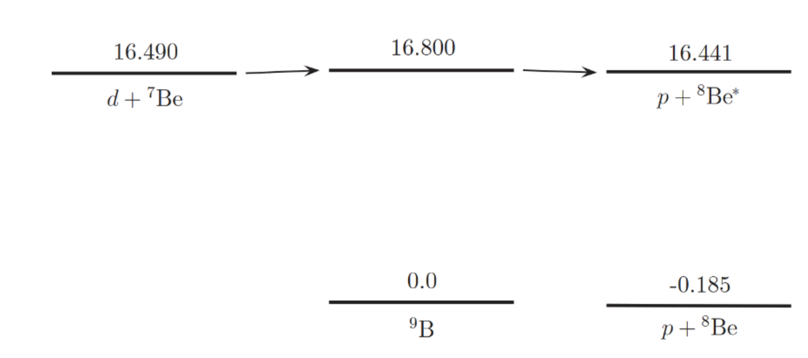


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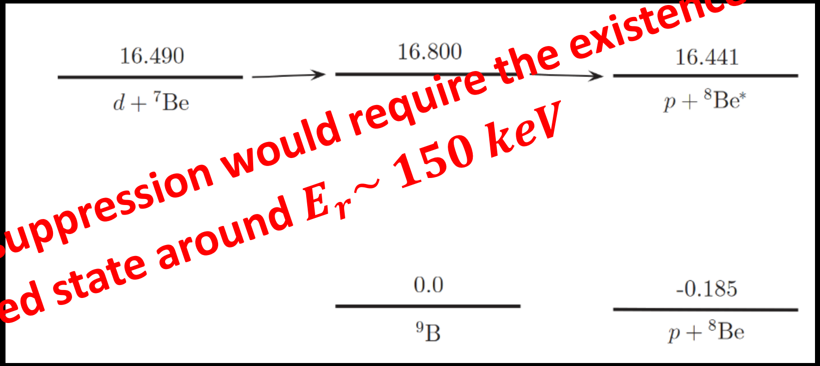


A non negligible suppression would require the existence of a new $^{9}Be$ excited state around $E_r \sim 150\ keV$

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PHYSICAL REVIEW C 84, 042801(R) (2011)

## Search for a resonant enhancement of the $^{7}$Be + $d$ reaction and primordial $^{7}$Li abundances


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Big Bang nucleosynthesis calculations, constrained by the Wilkinson Microwave Anisotropy Probe results, produce $^{7}$Li abundances almost a factor of four larger than those extrapolated from observations. Since primordial $^{7}$Li is believed to be mostly produced by the beta decay of $^{7}$Be, one proposed solution to this discrepancy is a resonant enhancement of the $^{7}$Be($d$, $p$)2$\alpha$ reaction rate through the 5/2$^{+}$ 16.7-MeV state in $^{9}$B. The $^{2}$H($^{7}$Be,$d$)$^{7}$Be reaction was used to search for such a resonance; none was observed. An upper limit on the width of the proposed resonance was deduced.



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Cyburt *et al.* argue that some of the assumptions made in this earlier measurement may not be valid. Furthermore, $(d, p)$ protons populating the 16.63-MeV 2$^{+}$ state in $^{8}$Be would have been missed in that study, since they were below the detection threshold [3]. In more recent work, Boyd *et al.* question whether the resonance would be populated in the $^{7}$Be + d reaction [7]. Clearly more study of possible resonances in $^{7}$Be + d reactions and the 16.7-MeV state in $^{9}$B is needed to resolve these issues.

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$^{7}Be + t$ ⟶ *Maximum achievable effect: 0.2% reduction of primordial* $^{7}Li$

*To produce a* $^{7}Li$ *reduction* $^{7}Be + t$ *destruction rate comparable to* $^{7}Be + n$ *process*

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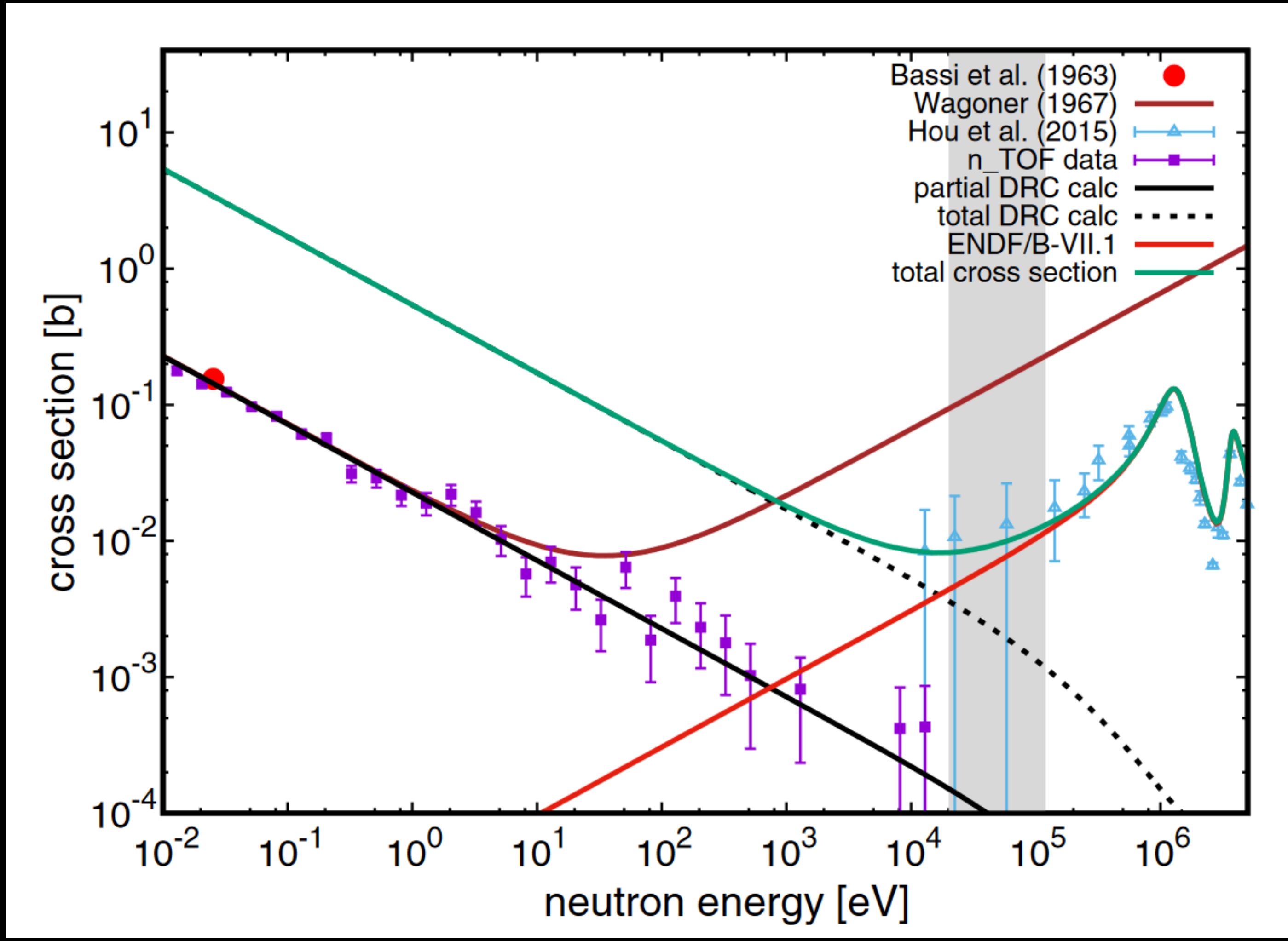
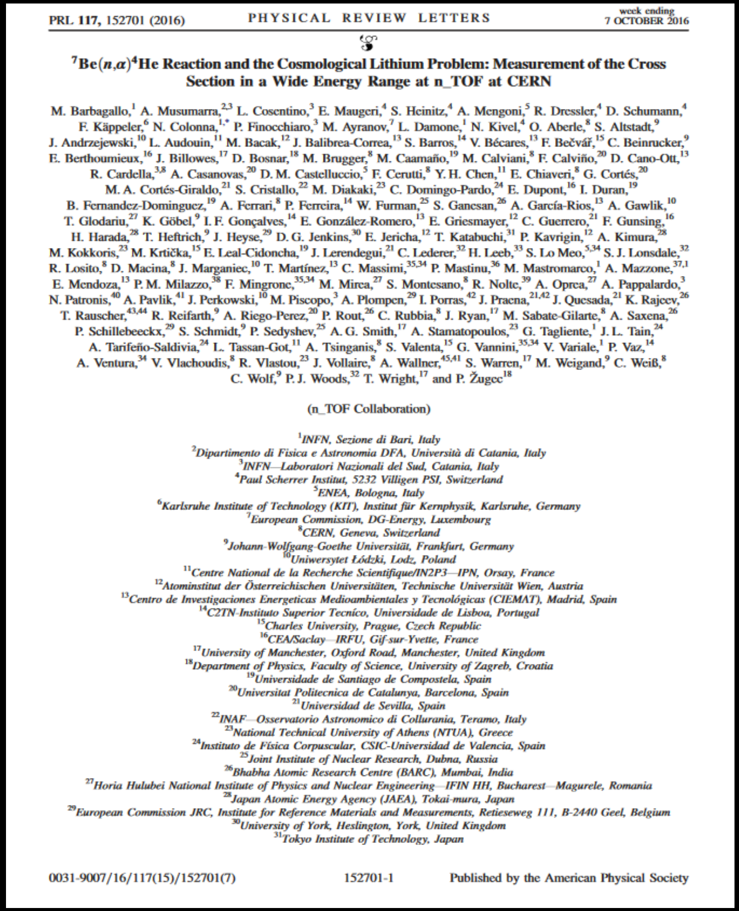
$^7Be + {}^3He$ ⟶ *Maximum achievable effect is a* $10^{-4}$ *reduction of primordial* $^7Li$

*Small effect due to the strong Coulomb barrier* ⟶ *a resonance can not solve the problem!*

# The Cosmological Lithium Problem




## $^{7}Be\,(n,\alpha)\,^{4}He$



PRL 117, 152701 (2016) PHYSICAL REVIEW LETTERS week ending 7 OCTOBER 2016

**$^{7}$Be($n$,$\alpha$)$^{4}$He Reaction and the Cosmological Lithium Problem: Measurement of the Cross Section in a Wide Energy Range at n_TOF at CERN**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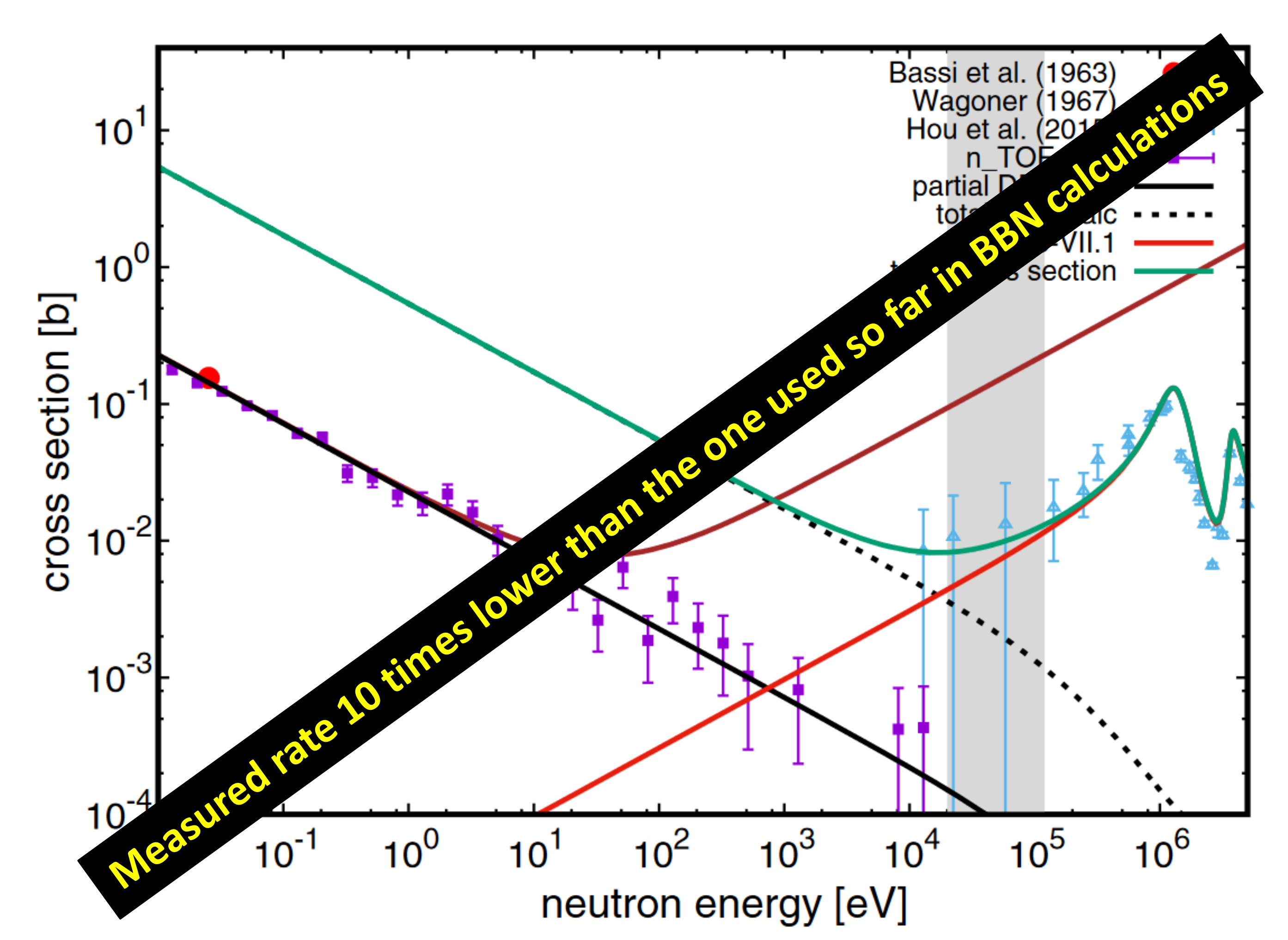


$^{7}Be\,(n,\alpha)\,^{4}He$


PRL **117**, 152701 (2016) PHYSICAL REVIEW LETTERS week ending 7 OCTOBER 2016


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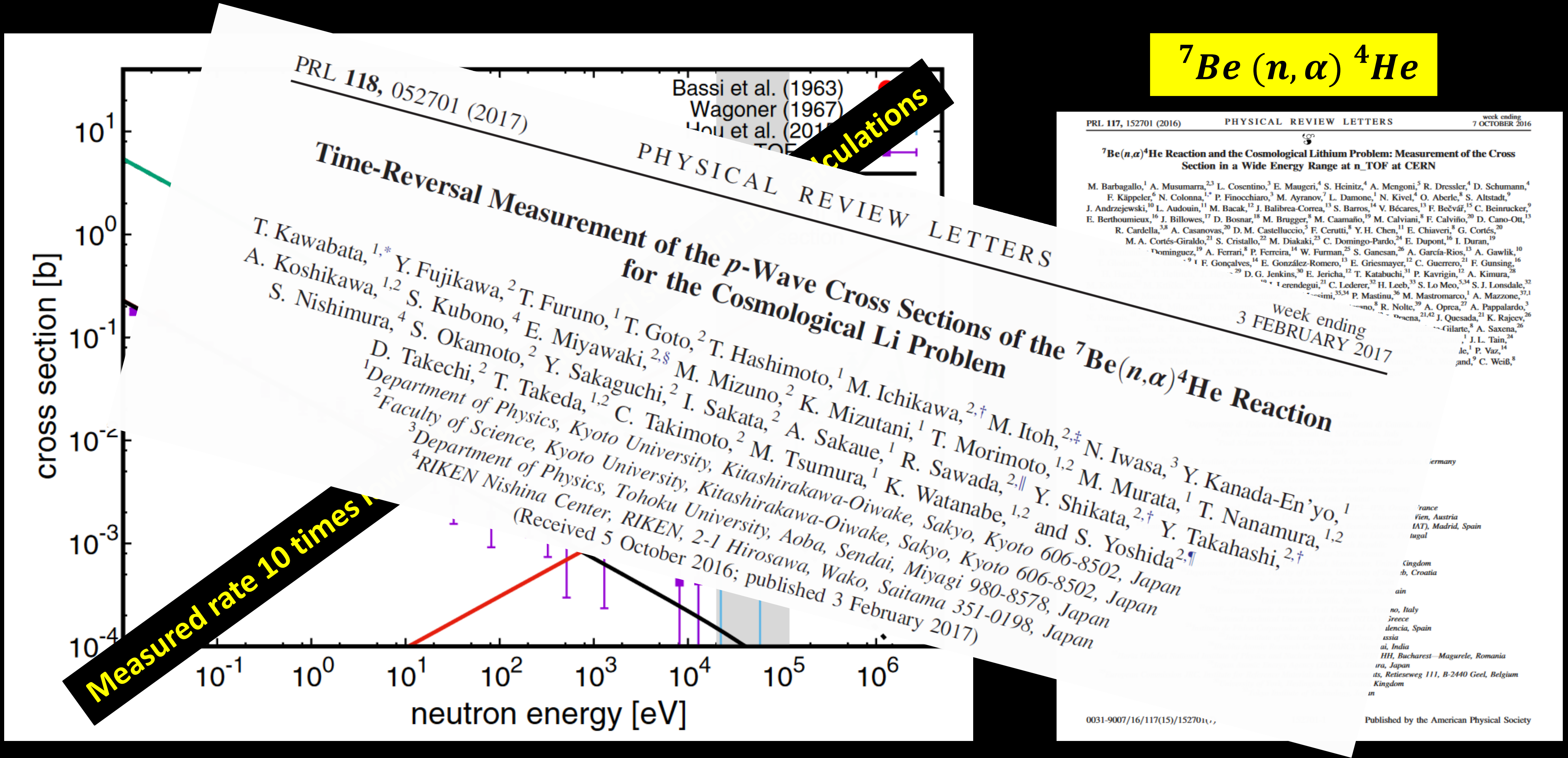

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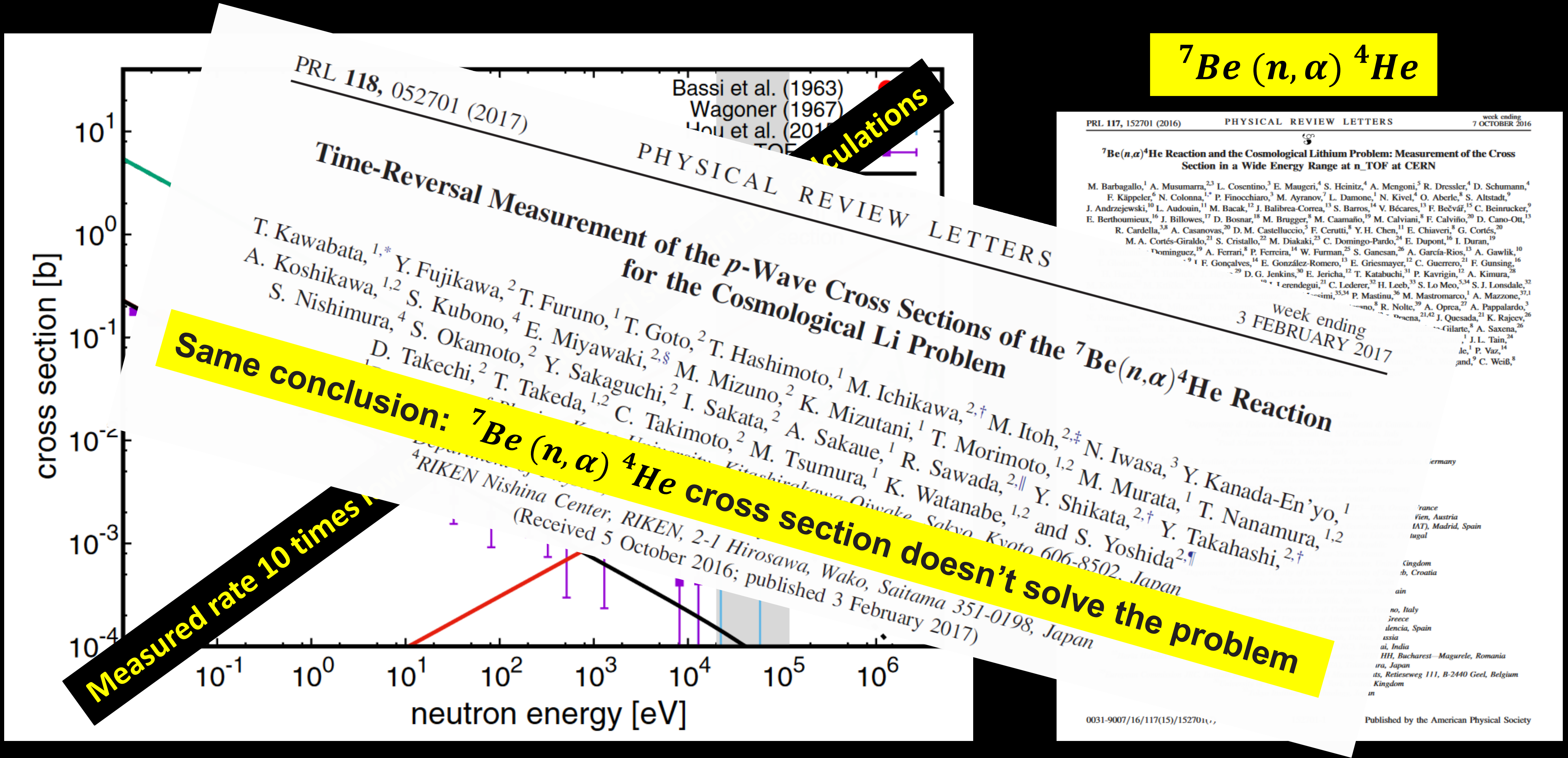
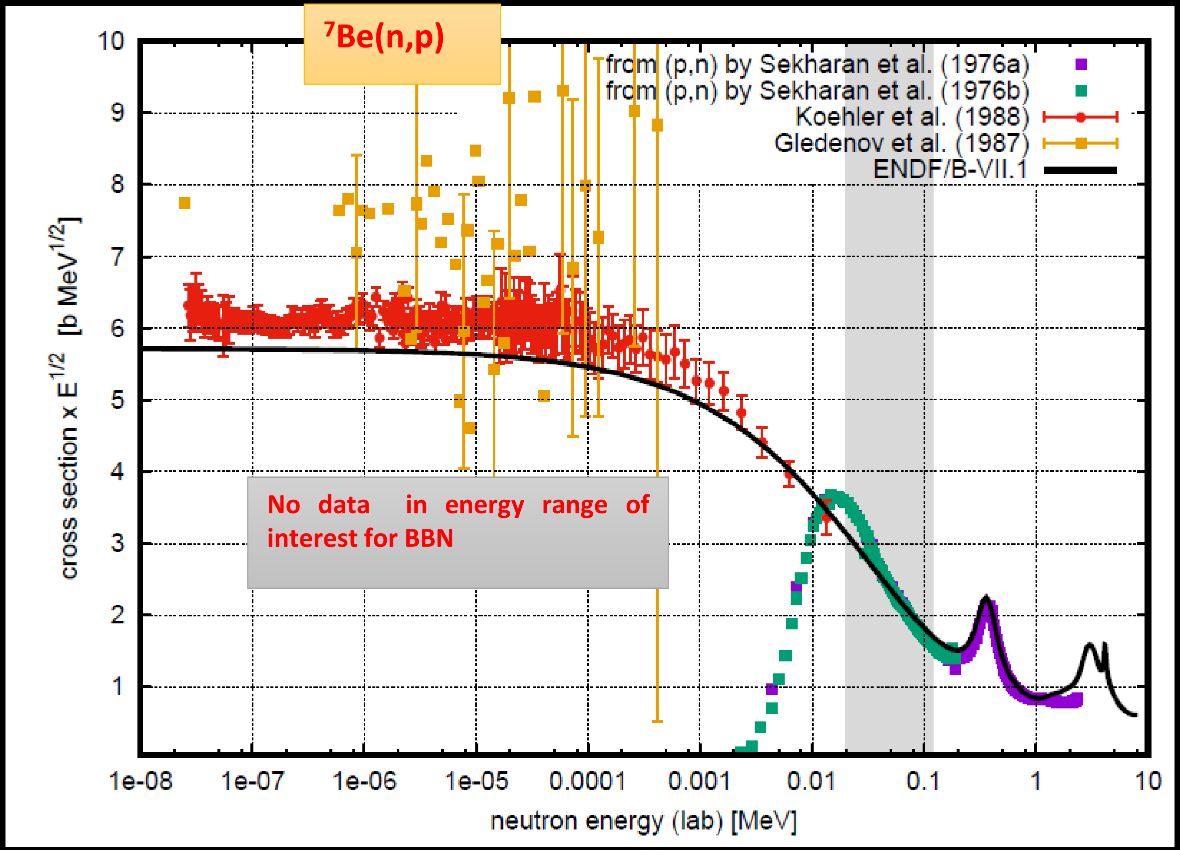



Same conclusion: $^7Be\,(n,\alpha)\,^4He$ cross section doesn't solve the problem

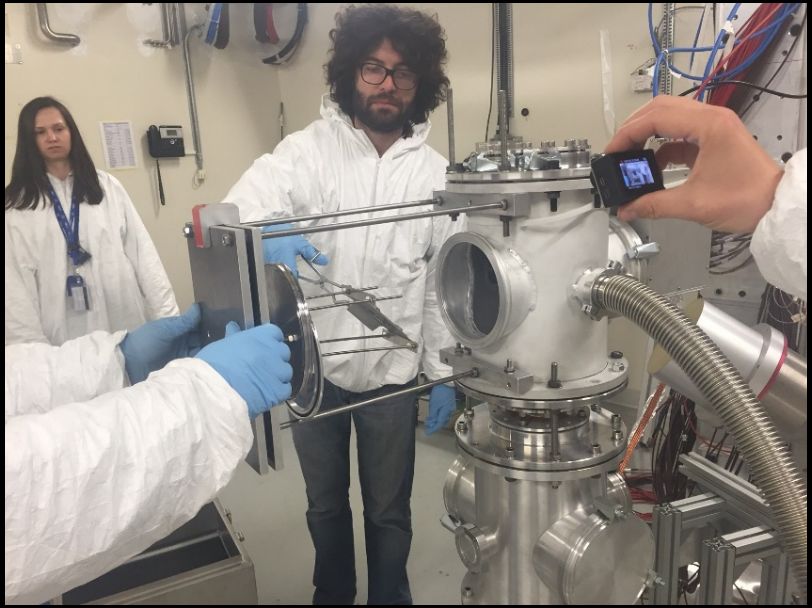
# Avaliable data for the $^{7}Be\ (n,p)\ ^{7}Li$

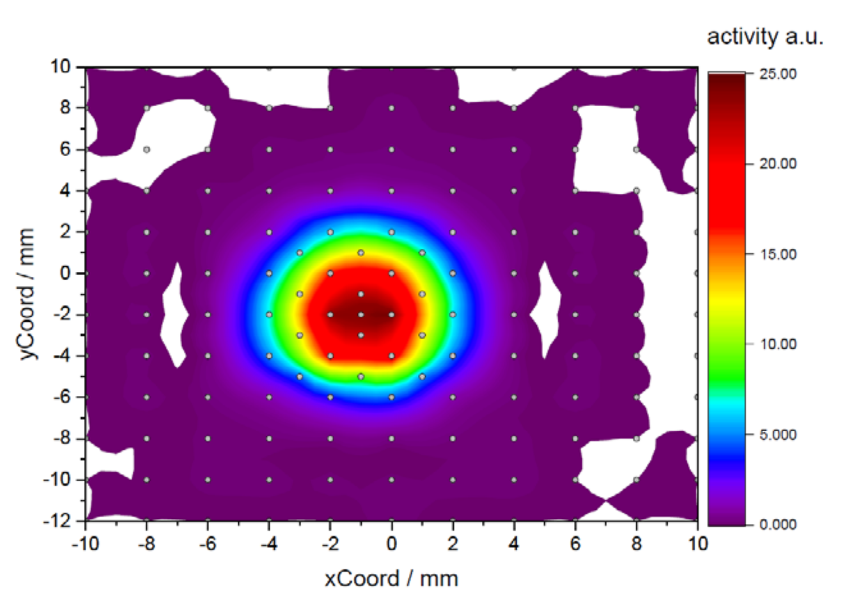



**Two** measurements:

- **Koehler at al.**, 1988, **0.025 eV- 13.5 keV**
- **Gledenov et al.**, 1987, **0.025 eV- ~500 eV**

# Sample preparation @PSI/ISOLDE






Sample characterization @PSI

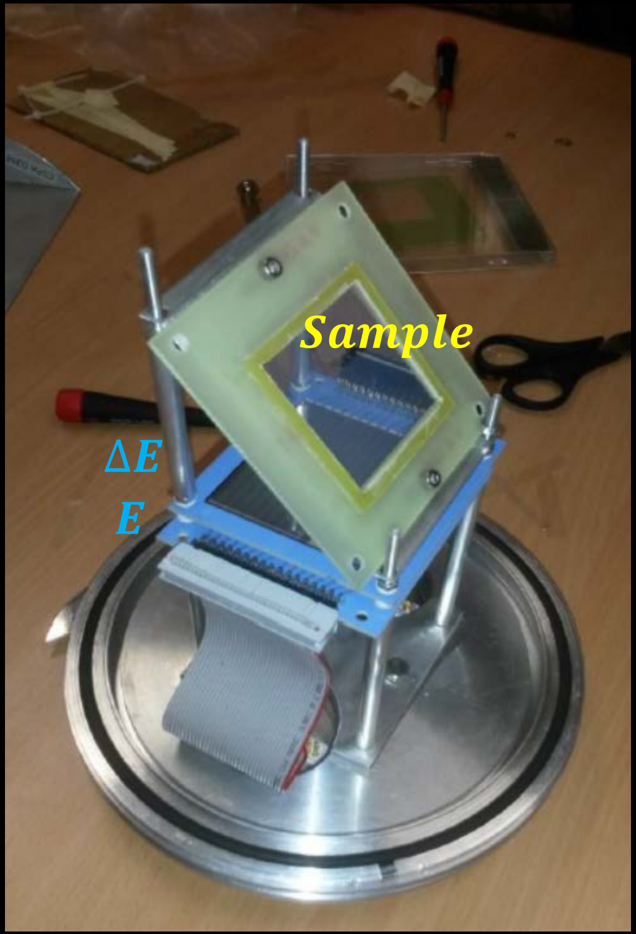
***1 GBq activity sample required***

*(16/04)* ***20 MBq***

*(14/05)* ***1.1 GBq***

→ **We obtained two samples!**

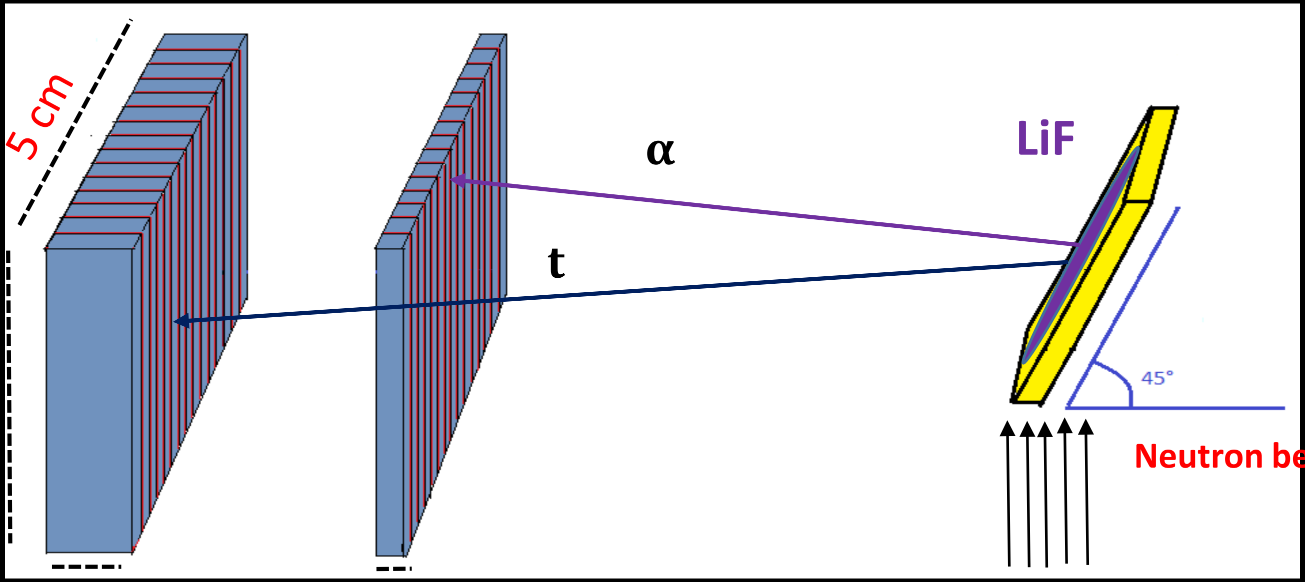
# Experimental set-up




$$n + {}^{6}Li \rightarrow \alpha + t$$

Cover $1.5 \times 1.5$ cm$^2$

5 cm




Neutron beam

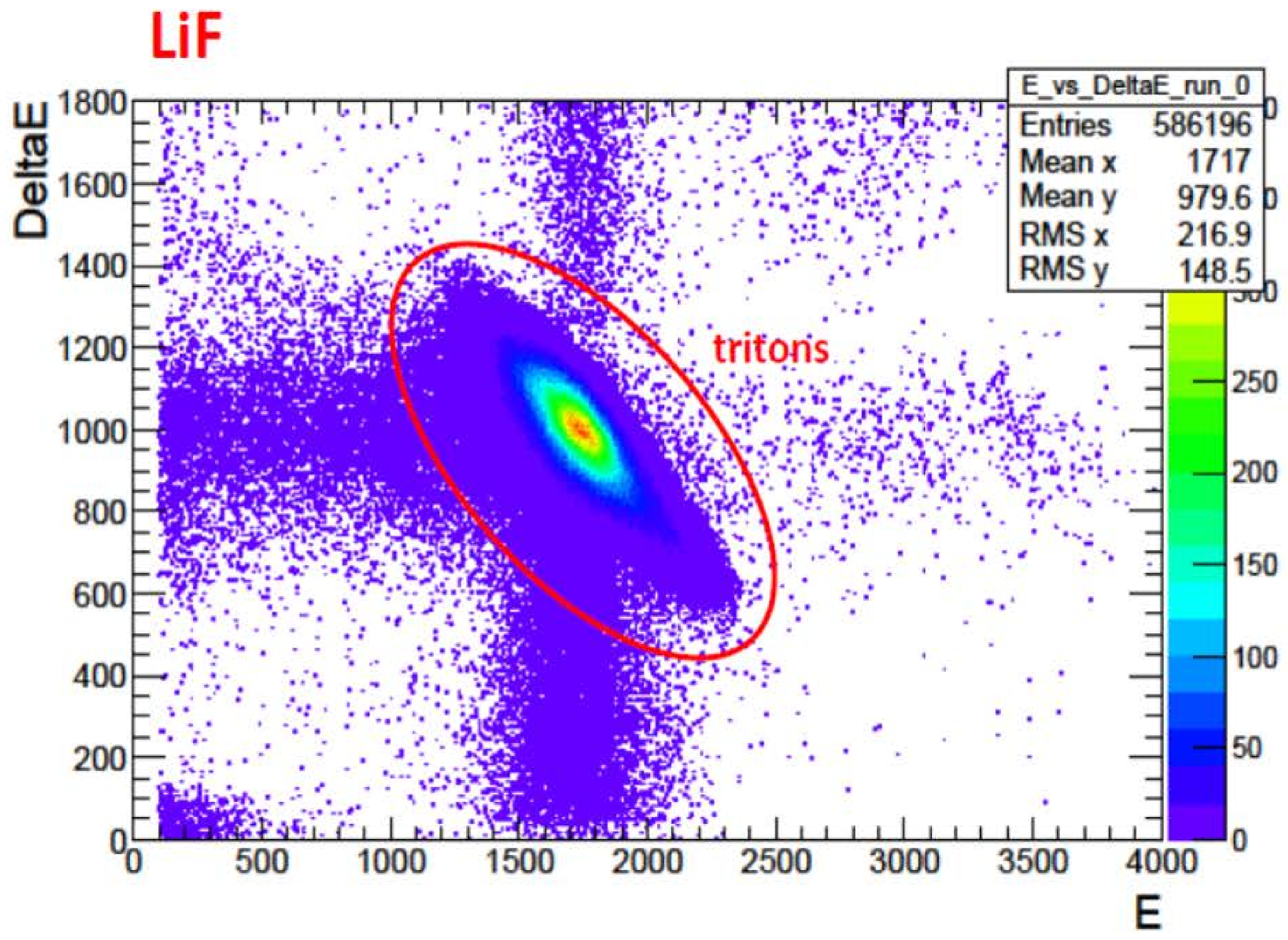
300 µm

20 µm

**LiF Sample**

| | |
|---|---|
| *xy* | $5 \times 5\ cm^2$ |
| *z* | 1.66 µm |

# LiF coincidences

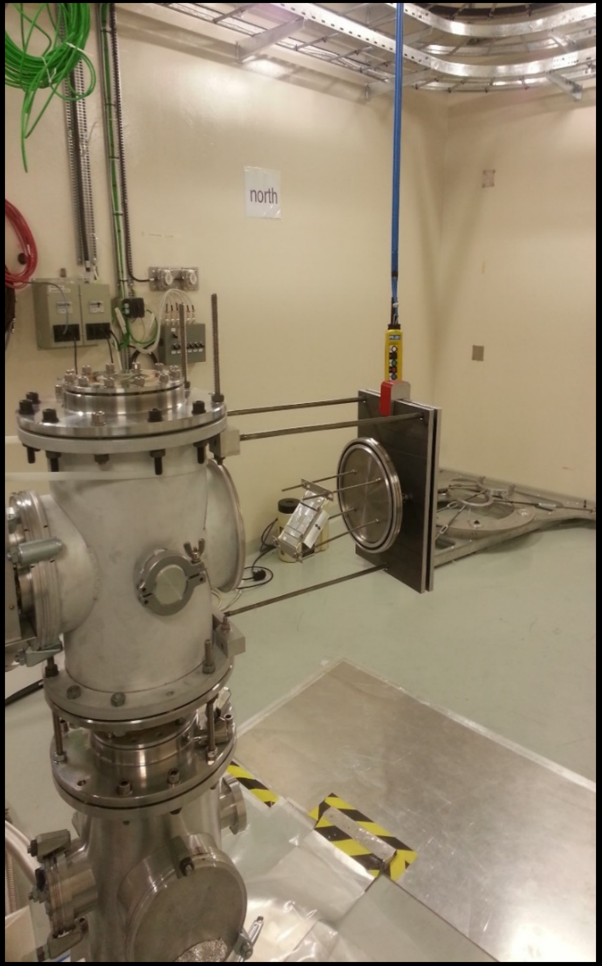



$$n + {}^{6}Li \rightarrow \alpha + t$$

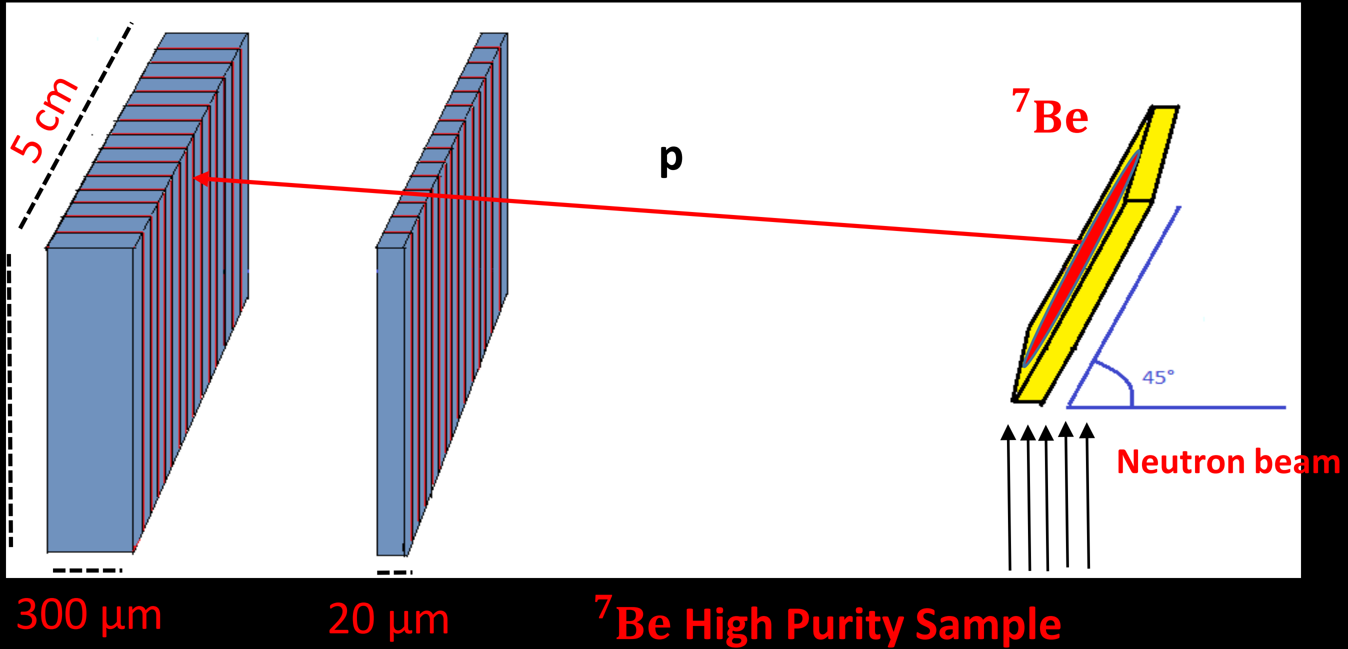
$Q = 4.78$ MeV

Coincidence window = 270 ns

# Experimental set-up



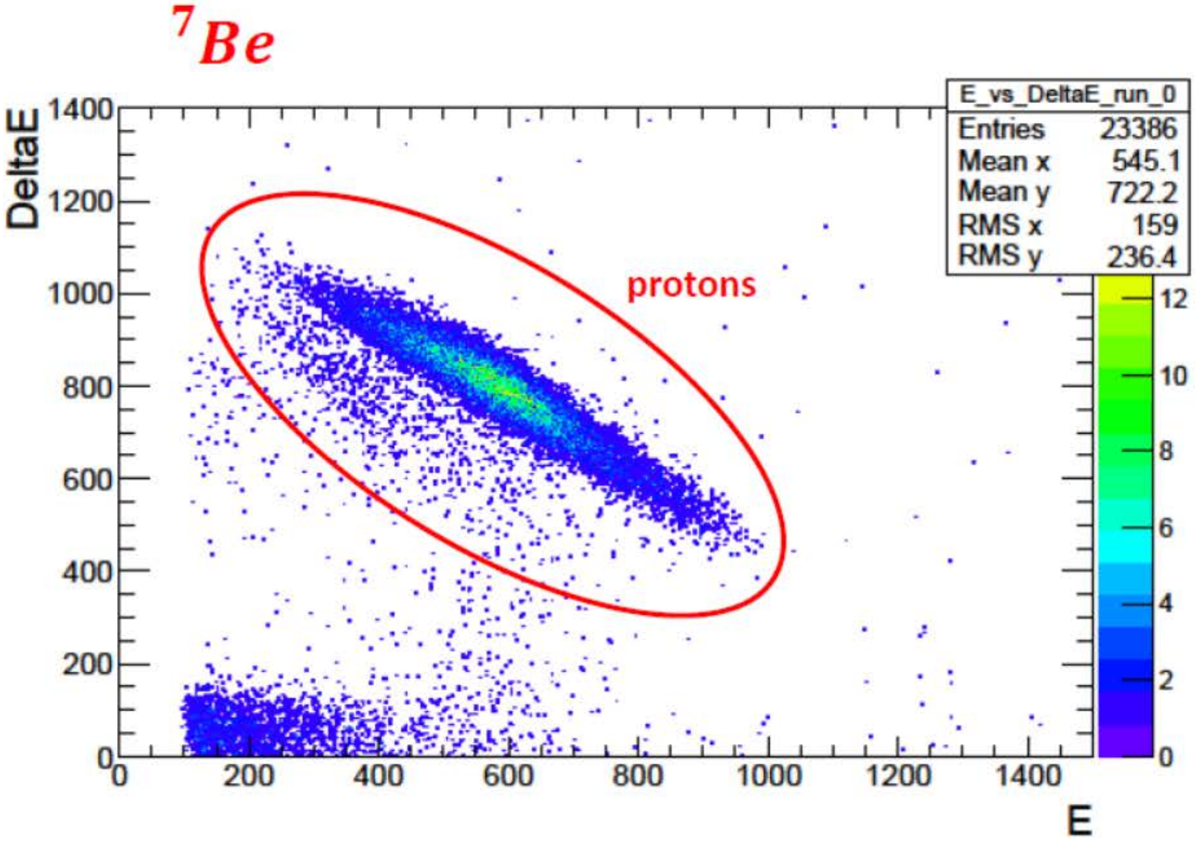

$$n + {}^{7}Be \rightarrow p + {}^{7}Li$$




${}^{7}$Be High Purity Sample

| Activity | 1.1 GBq |
|---|---|
| Radius | 2.5 mm |

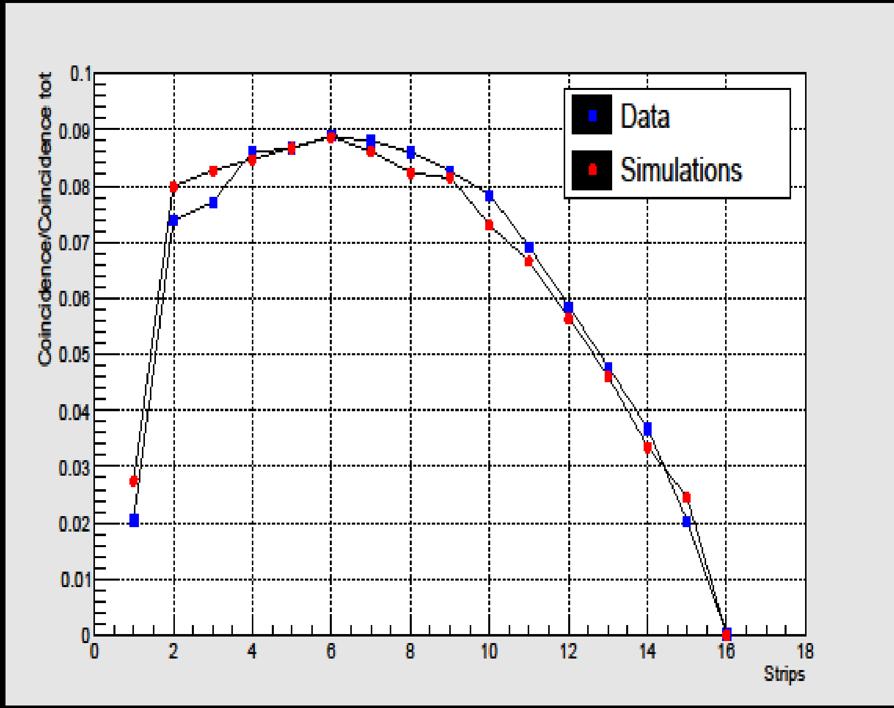
# $^7Be$ coincidences

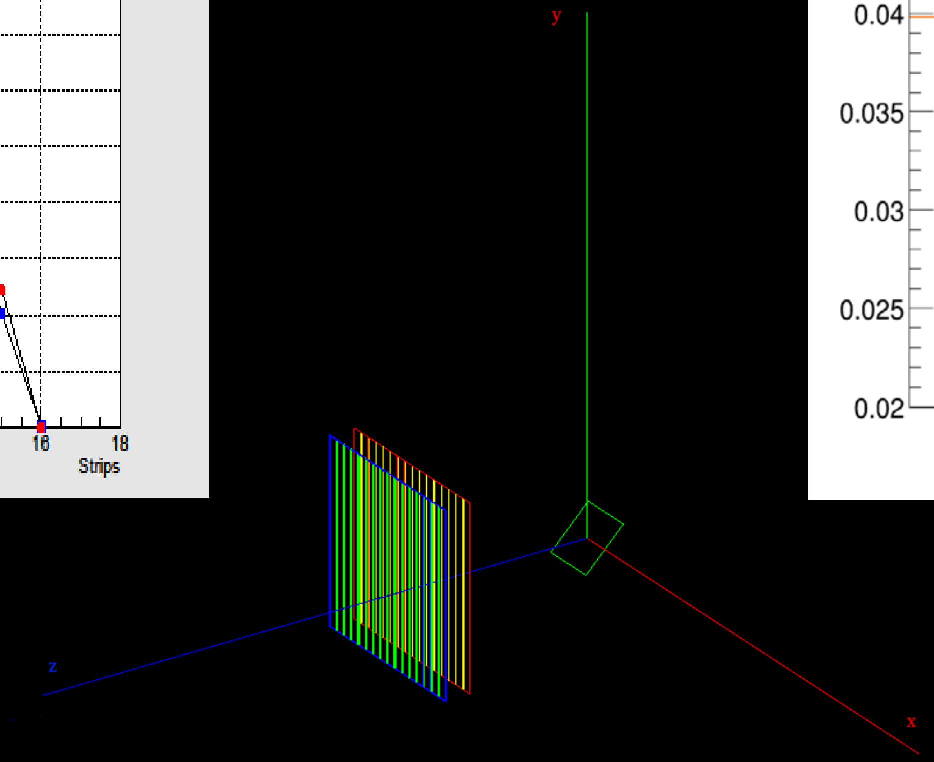


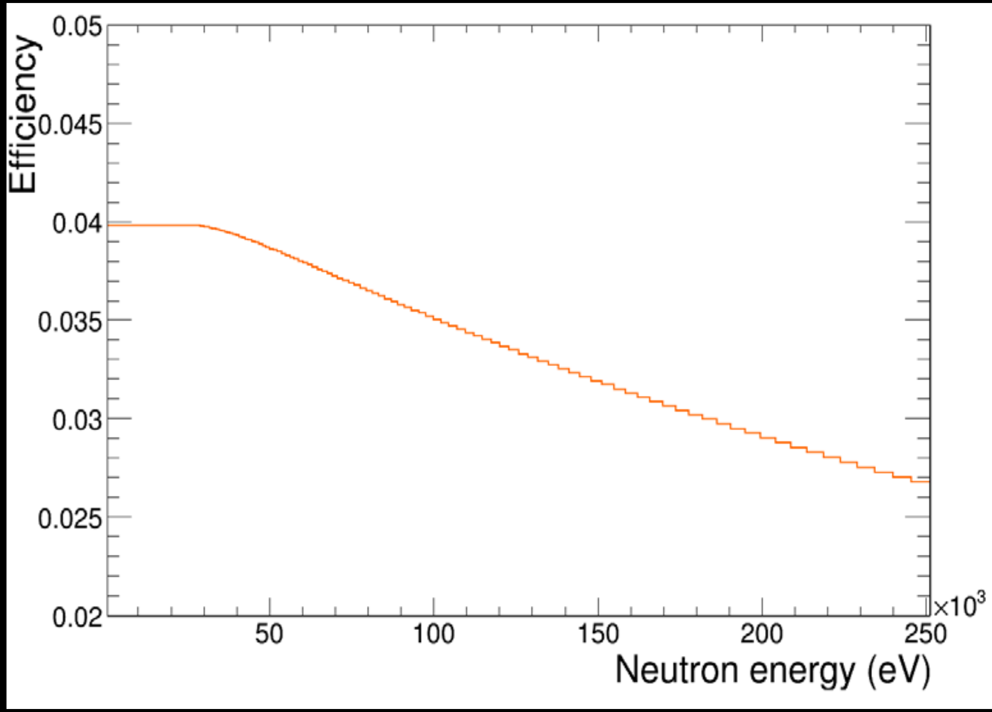

$$n + {}^7\mathrm{Be} \rightarrow p + {}^7\mathrm{Li}$$

$Q = 1.644$ MeV

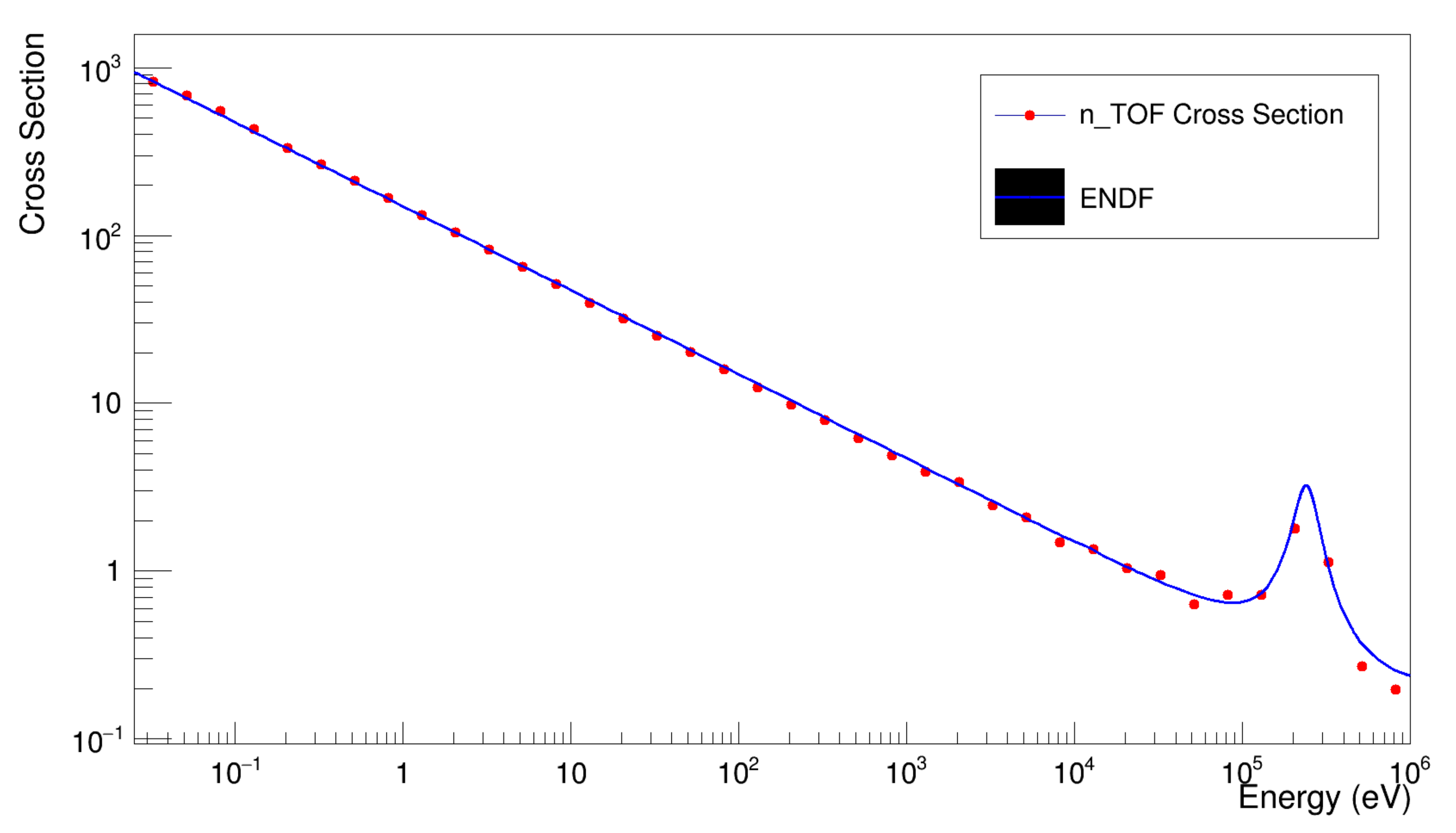
# Geant4 set-up simulations



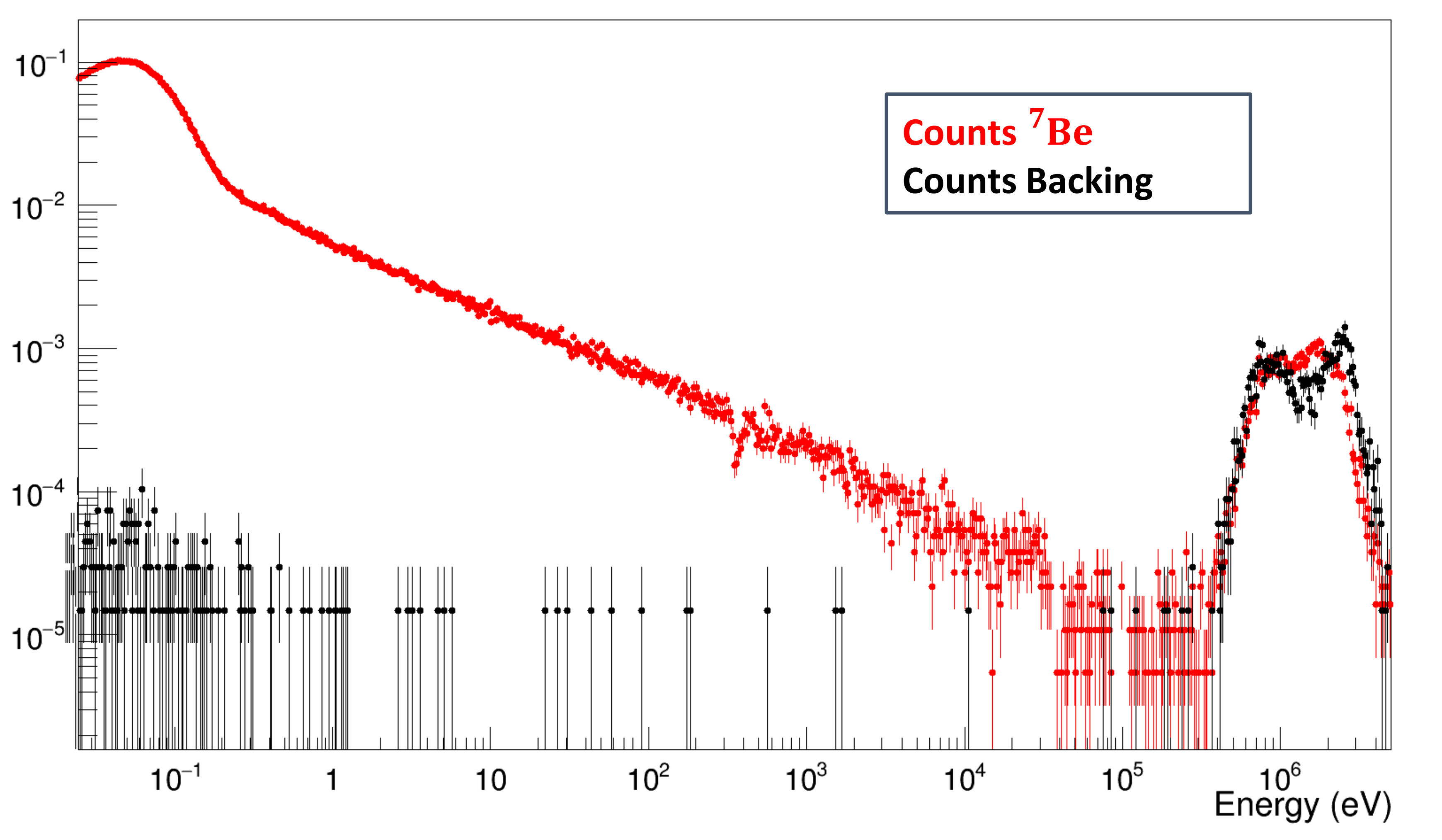



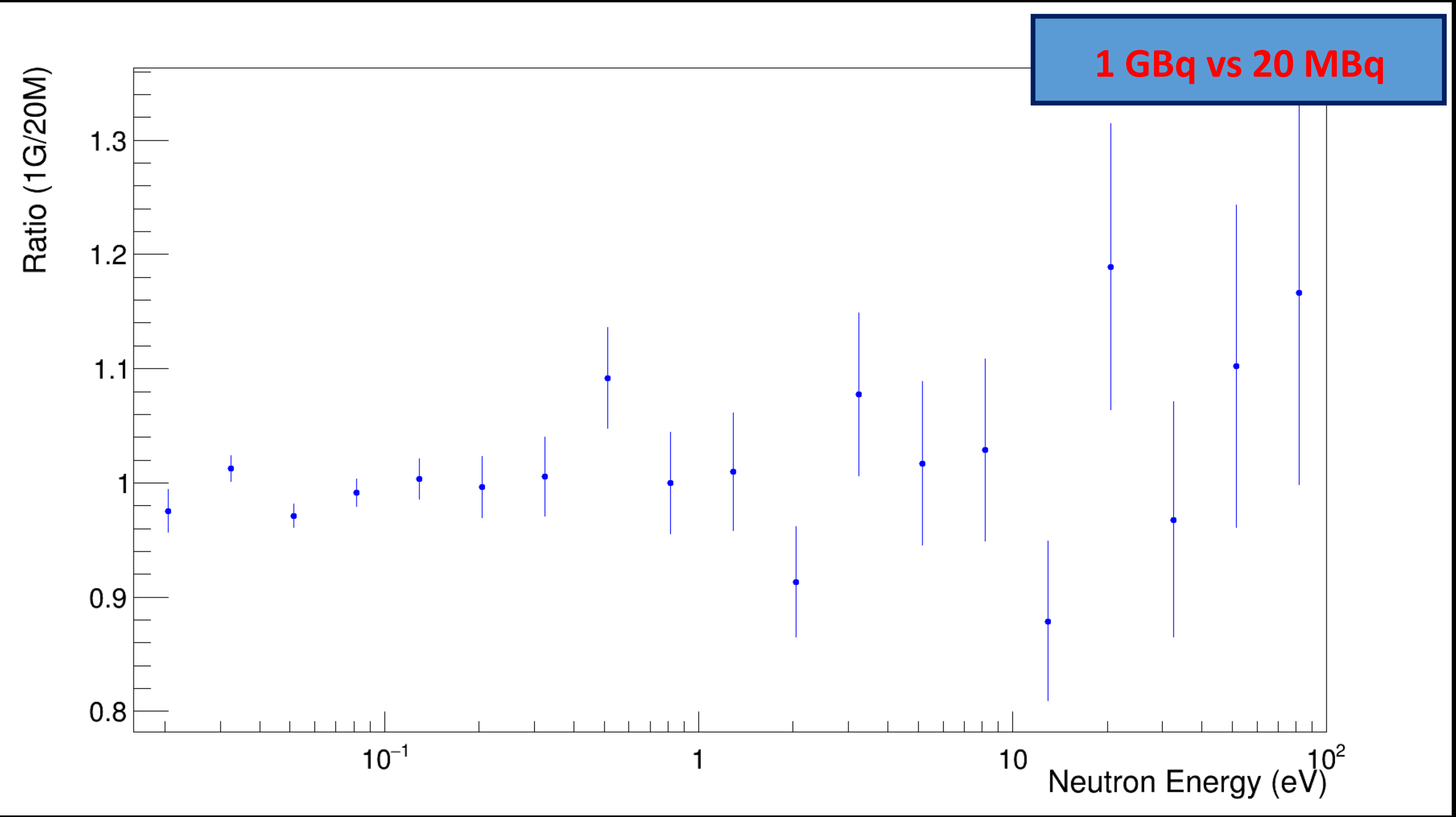
# $^{6}Li(n,t)\alpha$ cross-section



# Background check



# 20 MBq vs 1GBq



# Conclusions

- Uncertainties in nuclear data strongly affect the Big Bang Nucleosynthesis calculations for the abundance of $^{7}Li$ and our results could shade new light on the Cosmological Lithium Problem.
- 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.
- The $^{7}Be(n,p)^{7}Li$ cross-section has been measured with two different samples and the results are in a very good agreement.
- At n_TOF the $^{7}Be(n,p)^{7}Li$ cross-section has been measured for the first time in the energetic range of interest for the problem.

THANKS FOR YOUR KIND ATTENTION