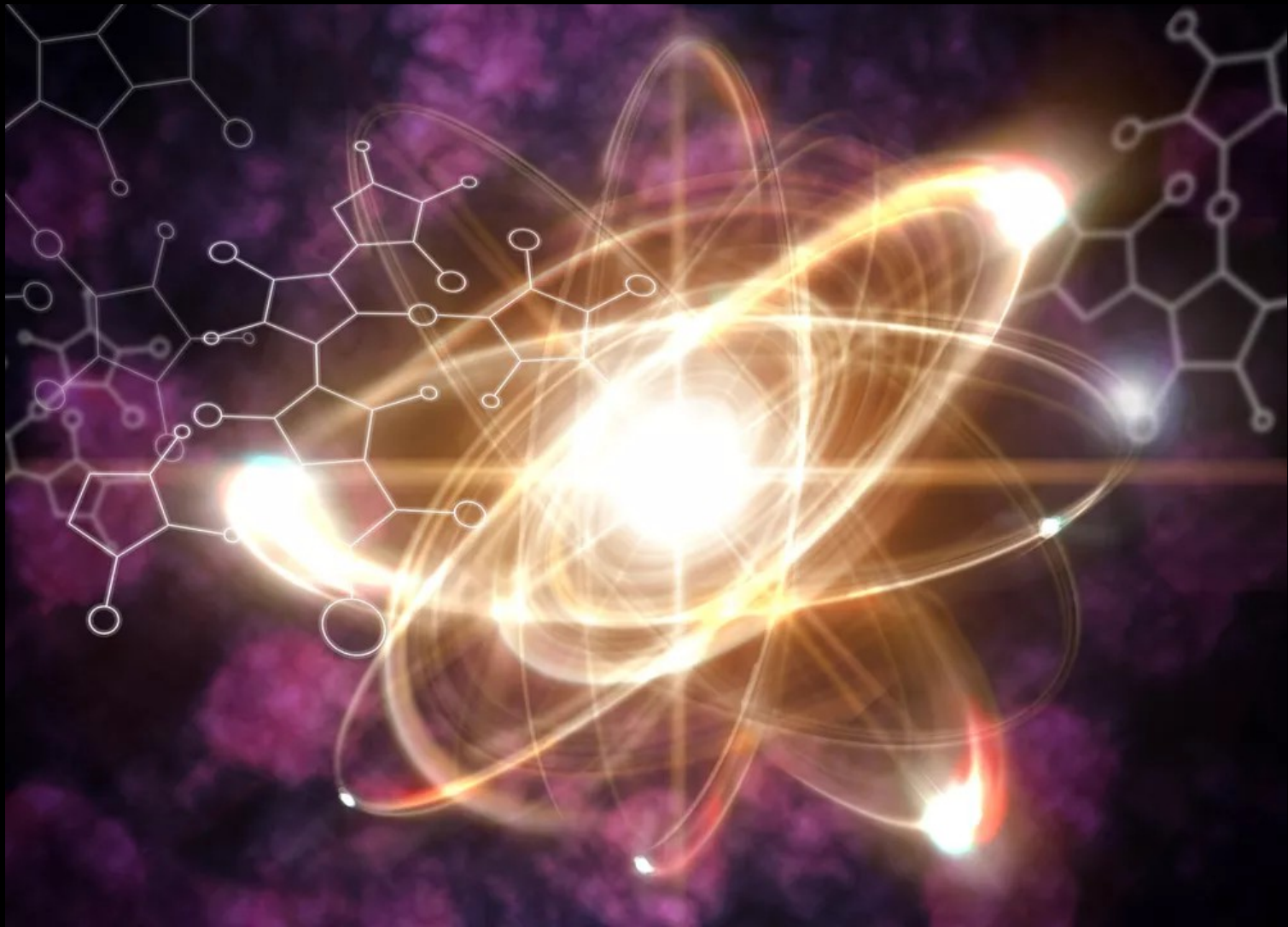
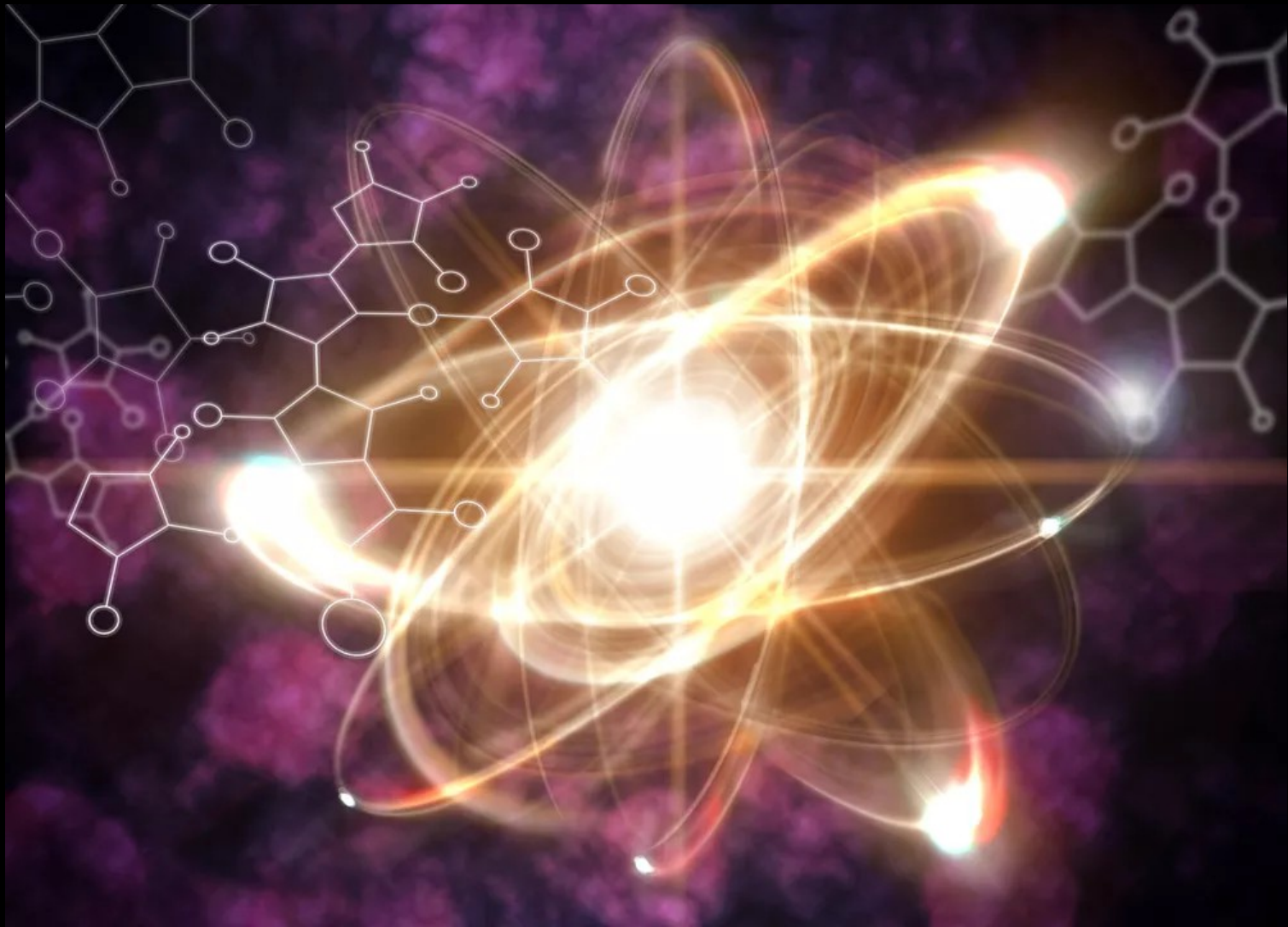


Big Bang Nucleosynthesis & Cosmological Lithium Problem

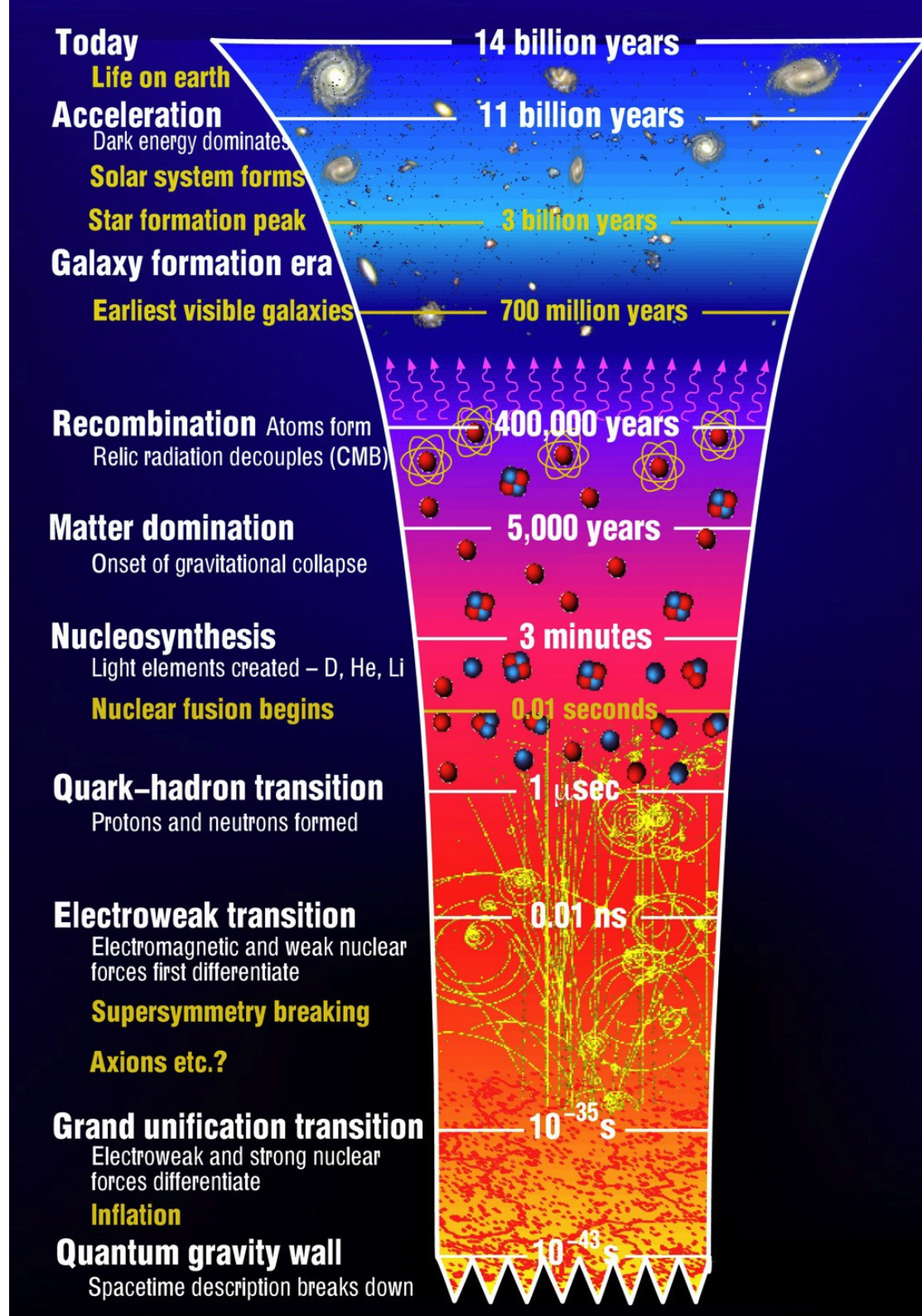


Big Bang Nucleosynthesis & Cosmological Lithium Problem



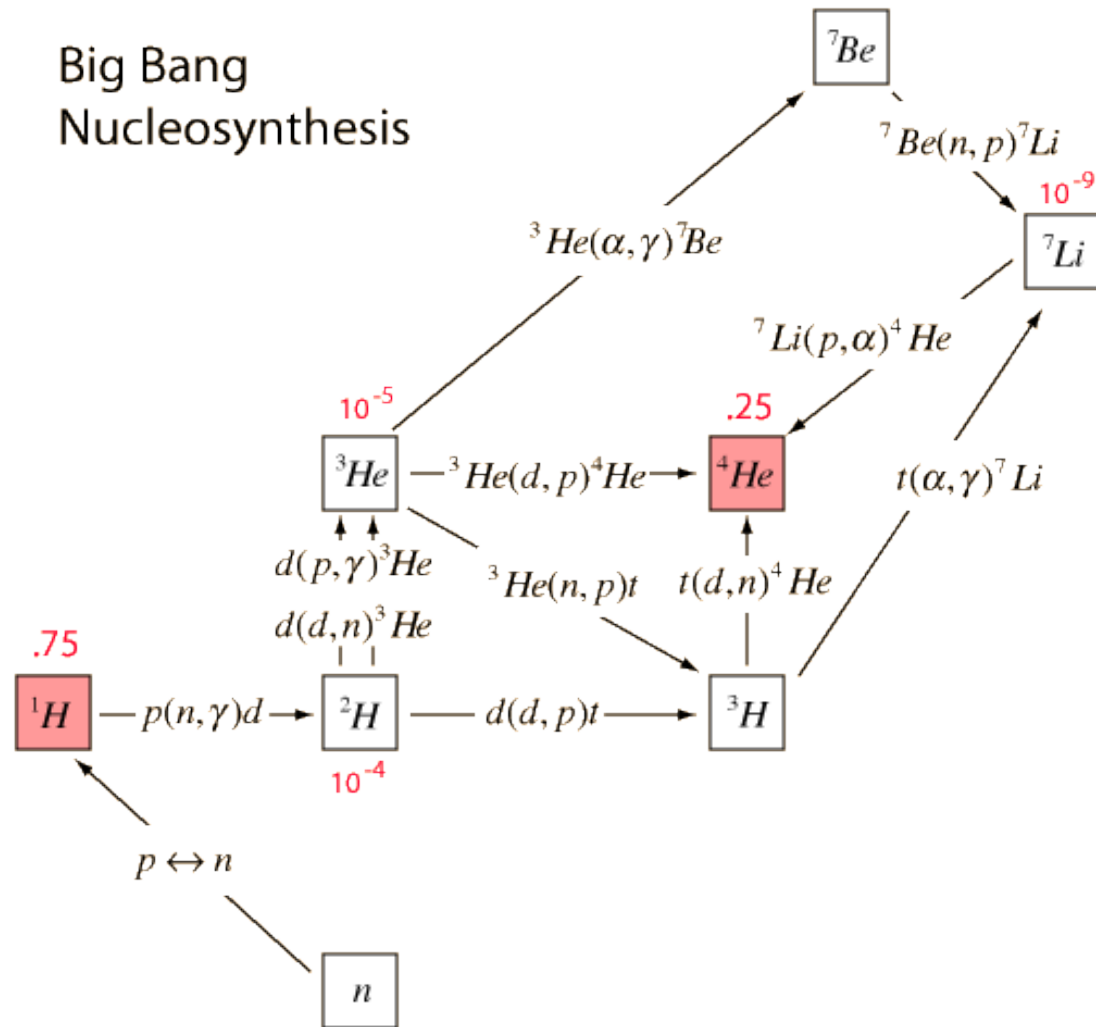
BBN

- let's not talk about QGP (sorry Martins!)
- this talk starts after cooling down below $T \sim 1 \text{ MeV}$ ($t \sim \text{s}$) temperature, too low to keep nucleon-lepton equilibrium, i.e. neutrons start to decay
- T still high enough to destroy ^2H via $^2\text{H} + \gamma \leftrightarrow p + n$
- $N(n)/N(p) \simeq e^{-\Delta m/T} \sim 1/5$



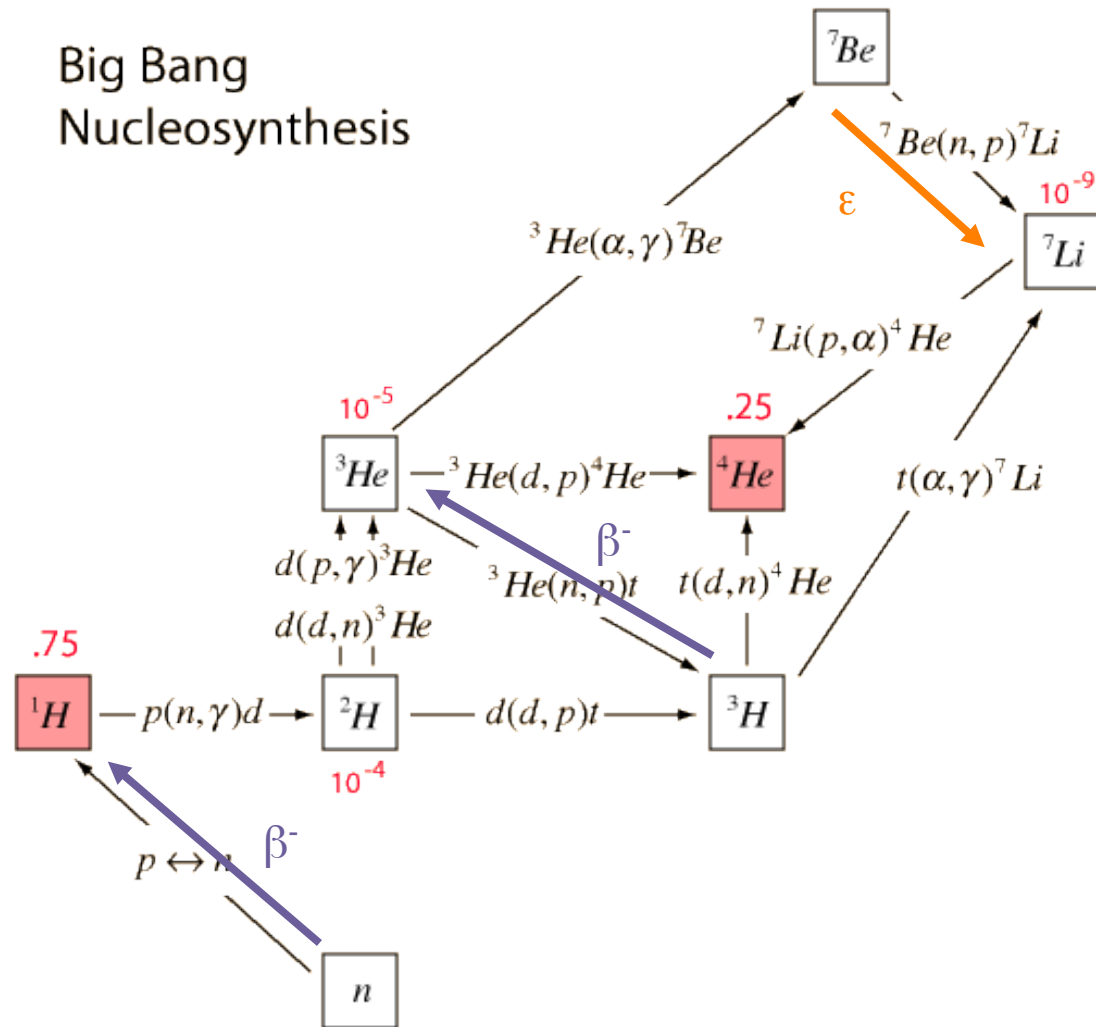
BBN

- after cooling down below $T \sim 0.1 \text{ MeV}$ ($t \sim \text{mins}$) temperature too low to destroy ${}^2\text{H}$
- the BBN reaction network starts

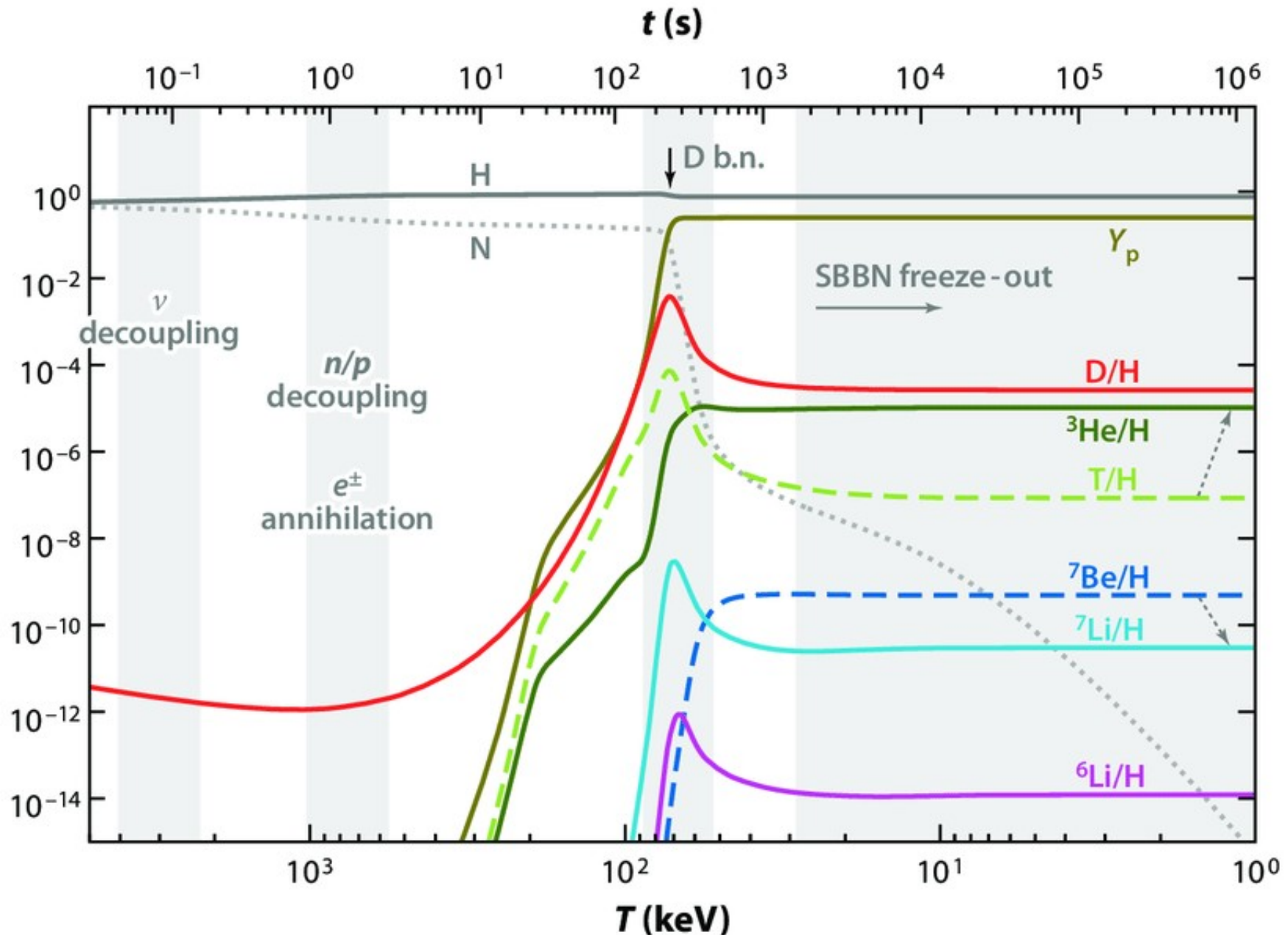


After BBN

- at $t \sim 20$ mins further cooling of the universe, Coulomb barriers, and the mass gap at $A = 8$ prevents production of other isotopes
- β decay is depleting some abundances
- at $t \sim 400$ ky electrons recombine with nuclei into atoms
 - CMB
 - ${}^7\text{Be}$ ϵ decay



During & After BBN



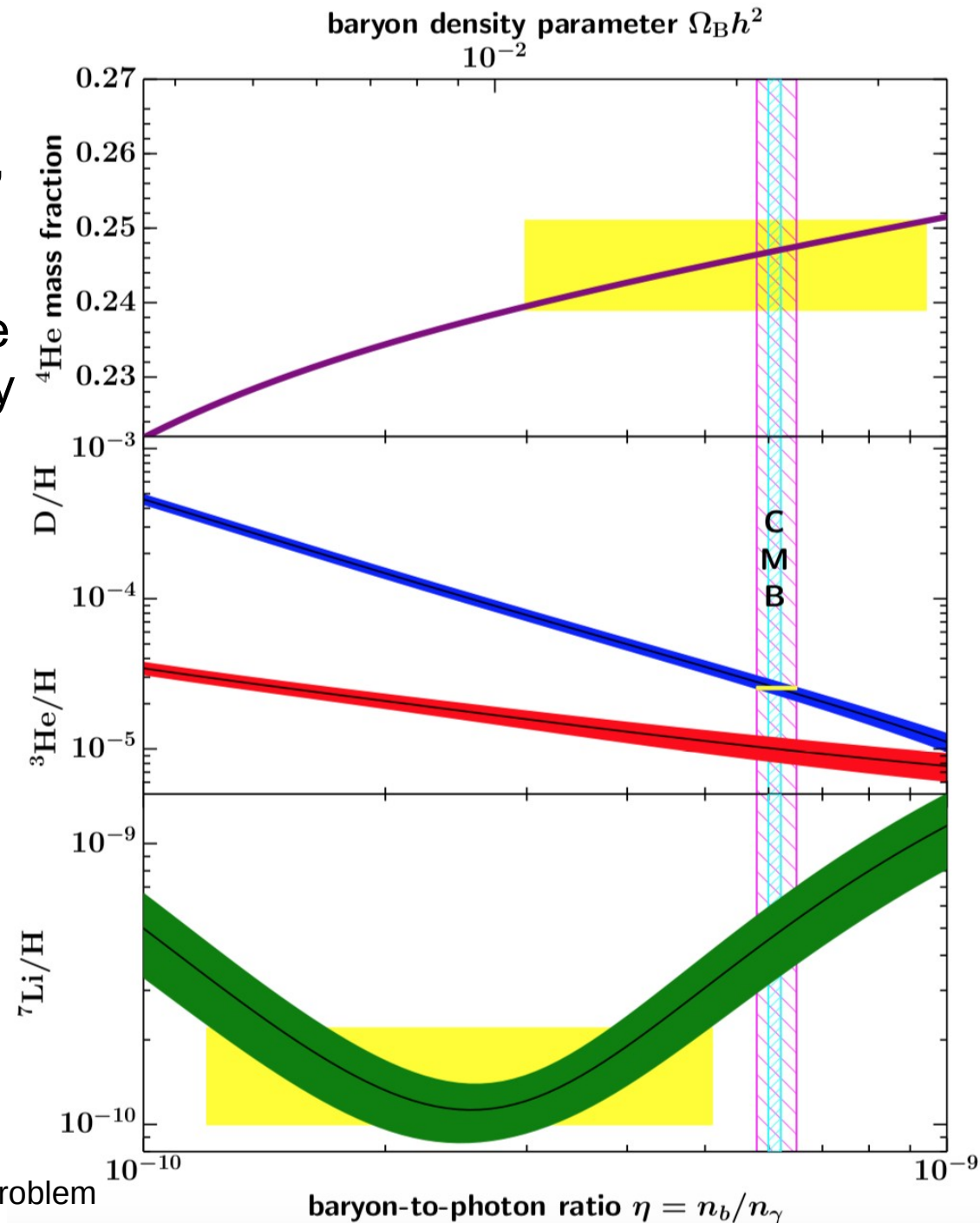
Cosmological Lithium Problem

„Stellar Li/H measurements are inconsistent with the CMB (and D/H), given the error budgets we have quoted. Recent updates in nuclear cross sections and stellar abundance systematics increase the discrepancy to over 5σ , depending on the stellar abundance analysis adopted.“

[PDG, Phys. Rev. D 98, 030001 (2018)]

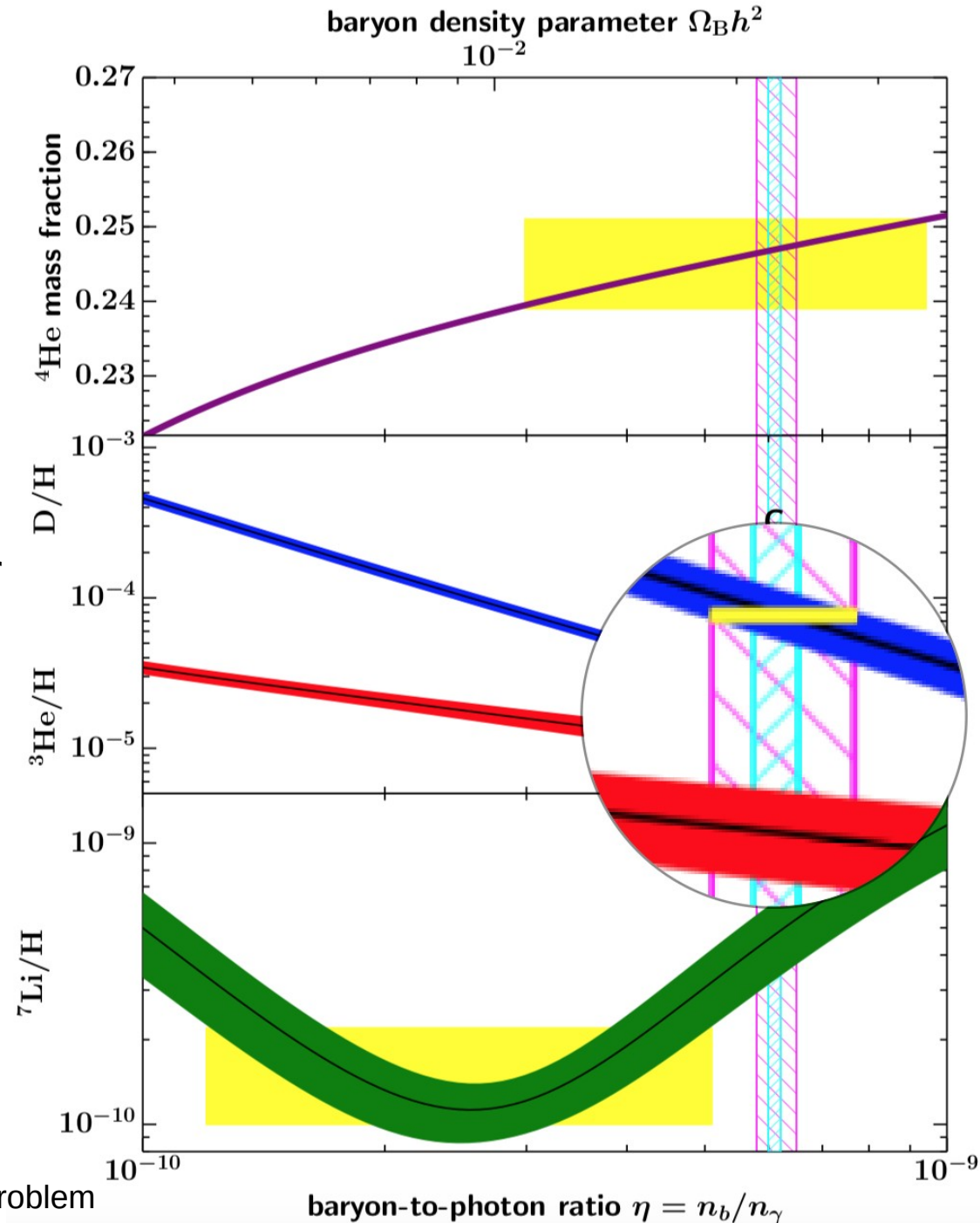
„... by BBN calculations, ${}^7\text{Li}$ is overestimated by more than a factor of 3, relative to the value inferred from the so-called “Spite plateau” halo stars.“

[n_TOF Coll. PRL 117, 152701 (2016)]



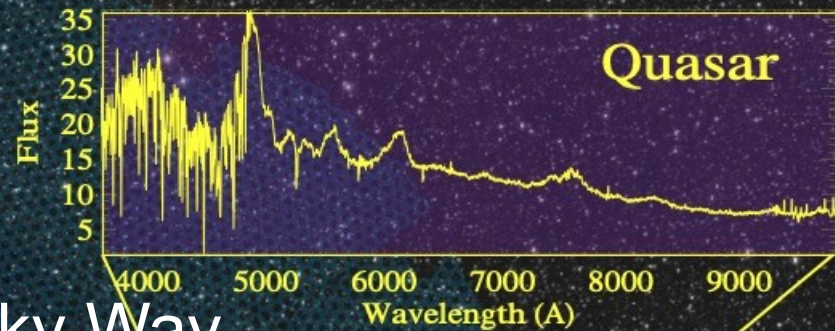
Cosmological Lithium Problem

- **yellow rectangles** = observed abundances
- **pink interval** = CMB measure of η
- **colored bands** = predicted abundances as function of η (uncertainty dominated by nuclear xs uncertainties)
- NOTE the (anti)correlations in predictions!



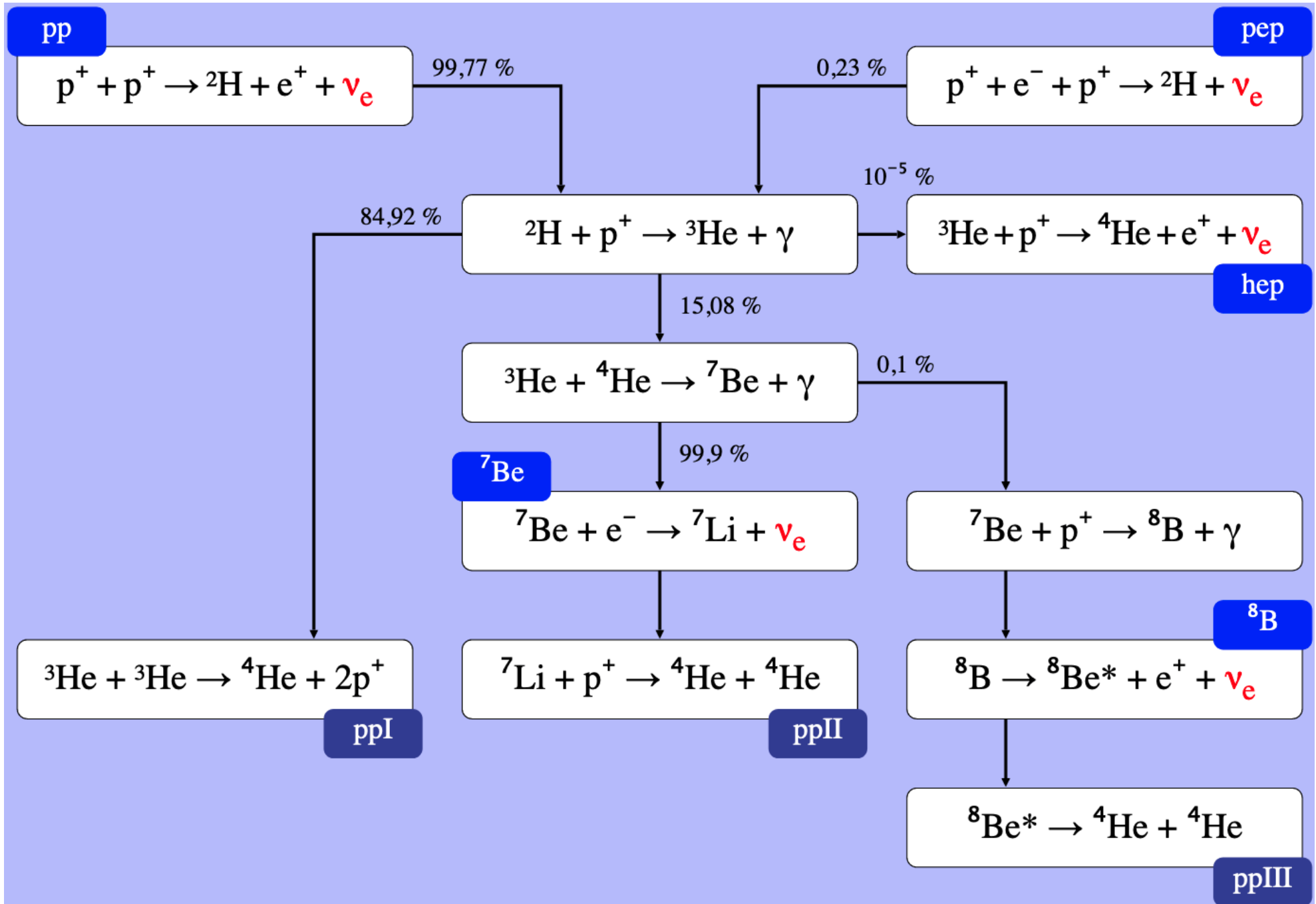
Observed abundances

- ^4He
 - ionized gas in metal-poor galaxies
 - now in CMB damping tail too
- D
 - galaxies backlit by quasars
- ^7Li
 - metal-poor halo stars in Milky Way
 - now also extragalactic observations
- ^3He
 - no good way...

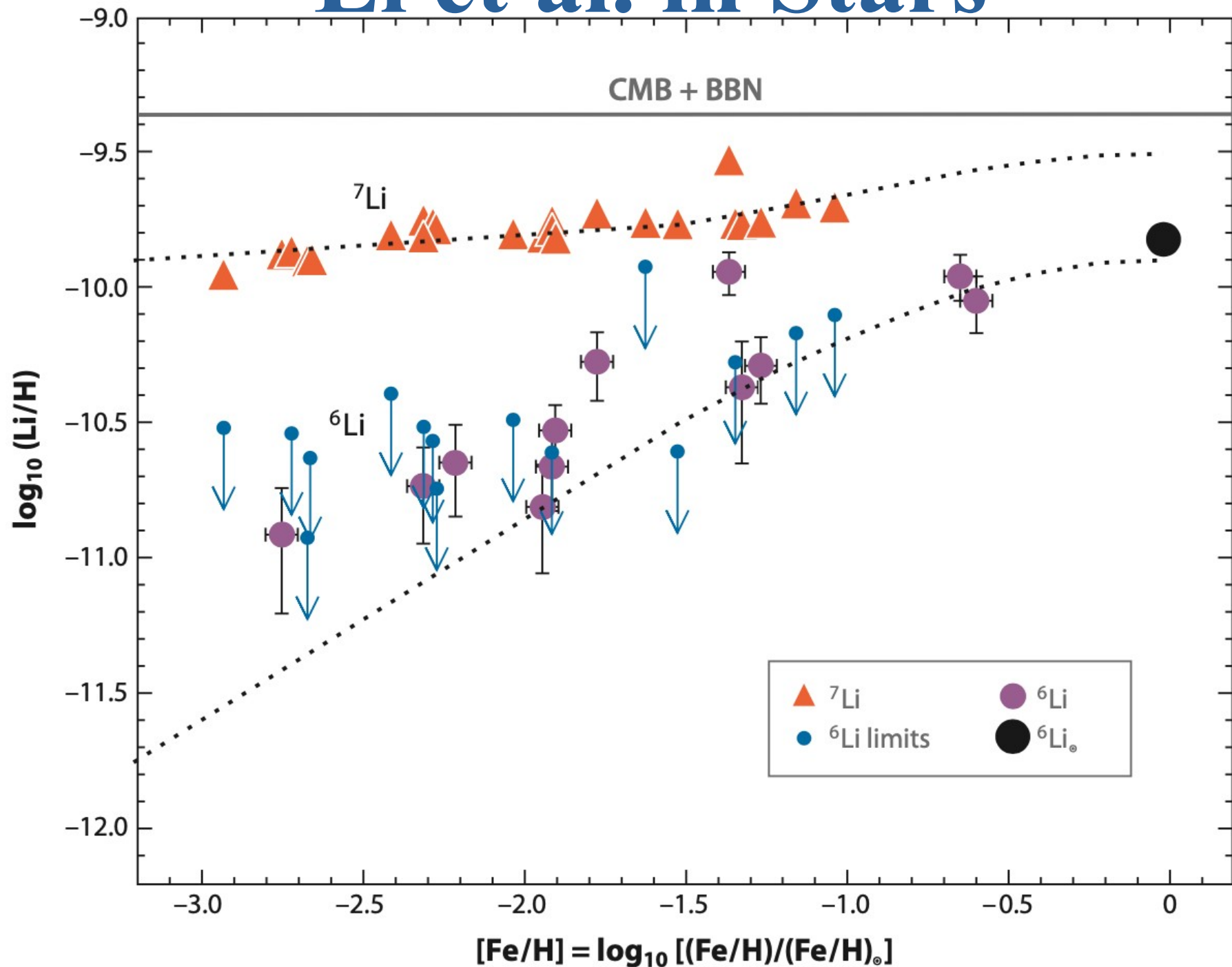


Why metal-poor?

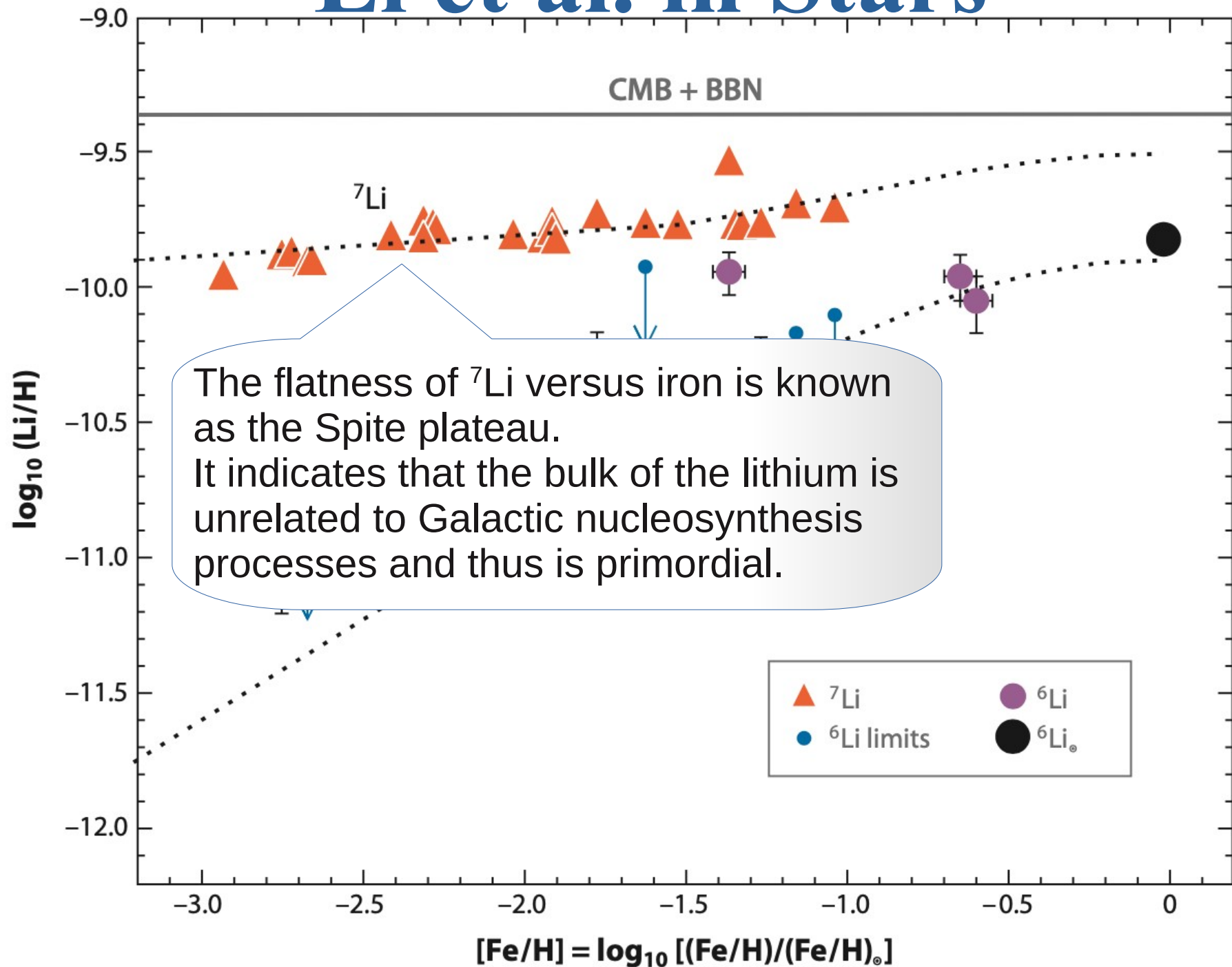
Li et al. in Stars



Li et al. in Stars



Li et al. in Stars



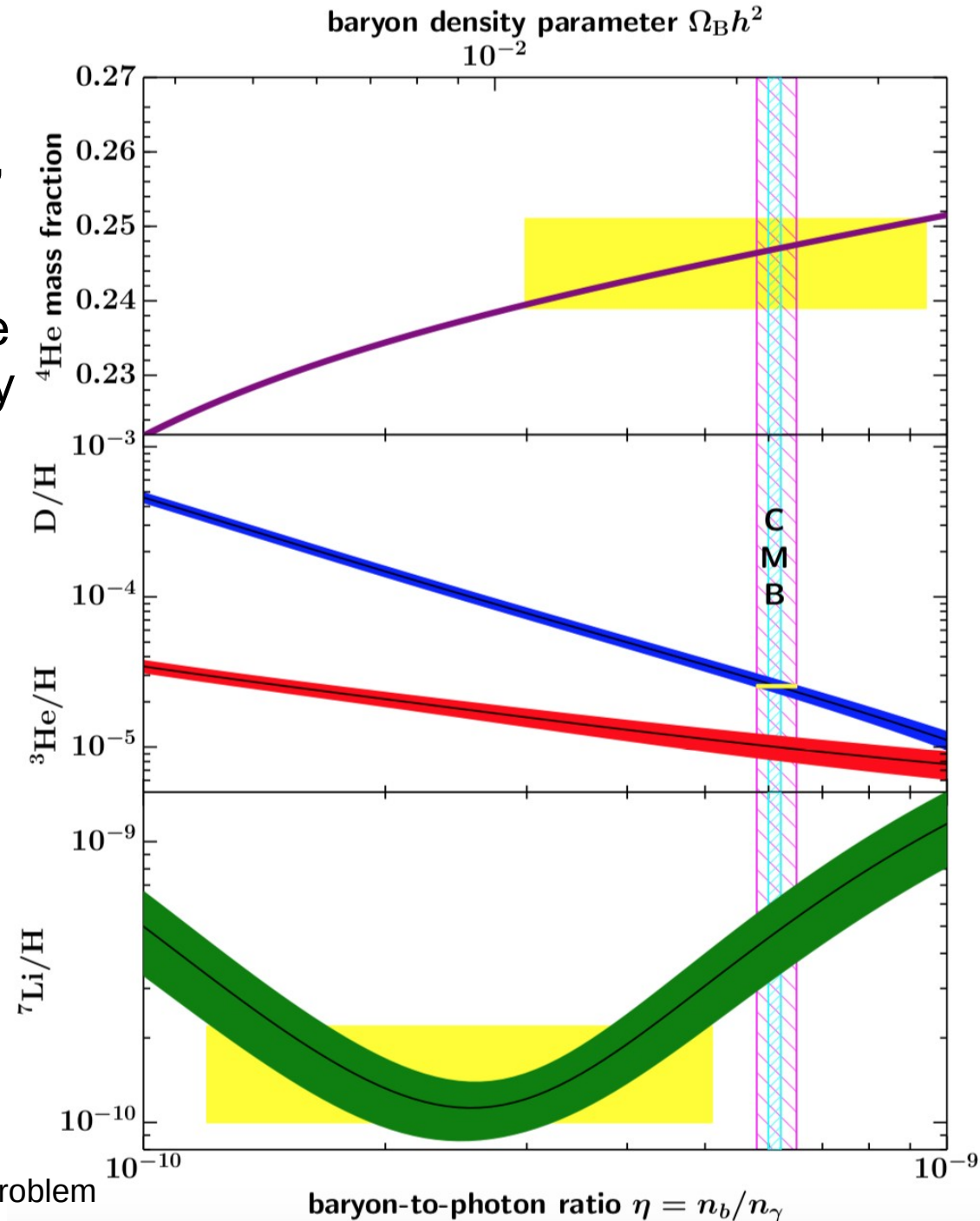
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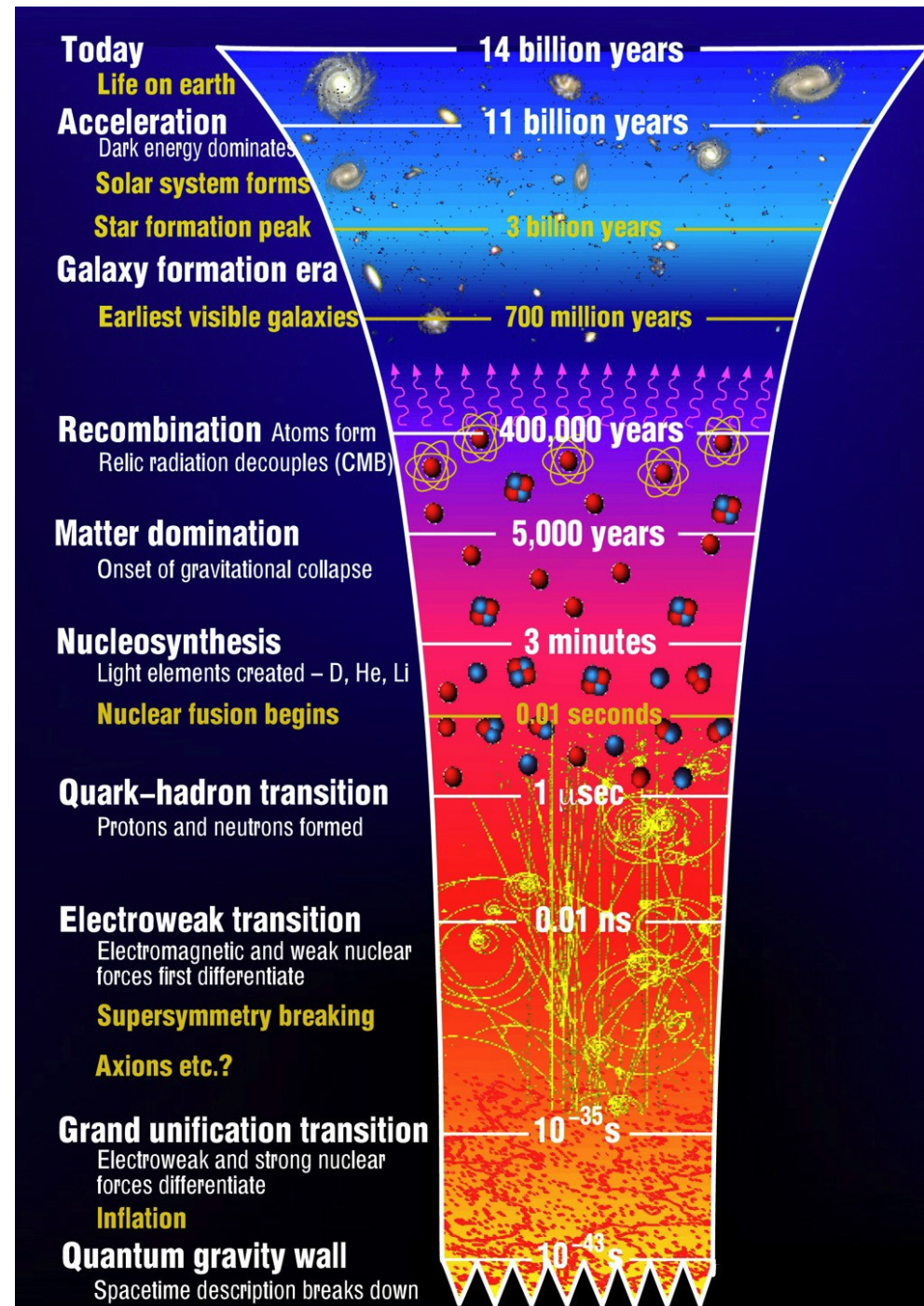
[n_TOF Coll. PRL 117, 152701 (2016)]



But wait! Assumptions?!

- 1) Gravity = General Relativity
- 2) Other forces = Standard Model
 $N_\nu = 3$ neutrino species
 $m_\nu \ll 1$ MeV
Left handed ν coupling only
leptons \sim baryons
- 3) Kinetic equi. = Maxwell-Boltzmann distribution for nuclei
- 4) Dark matter & energy present, but non-interacting
baryon-to-photon ratio $\eta = n_b / n_\gamma$
- 5) Adiabatic expansion in homogeneous universe

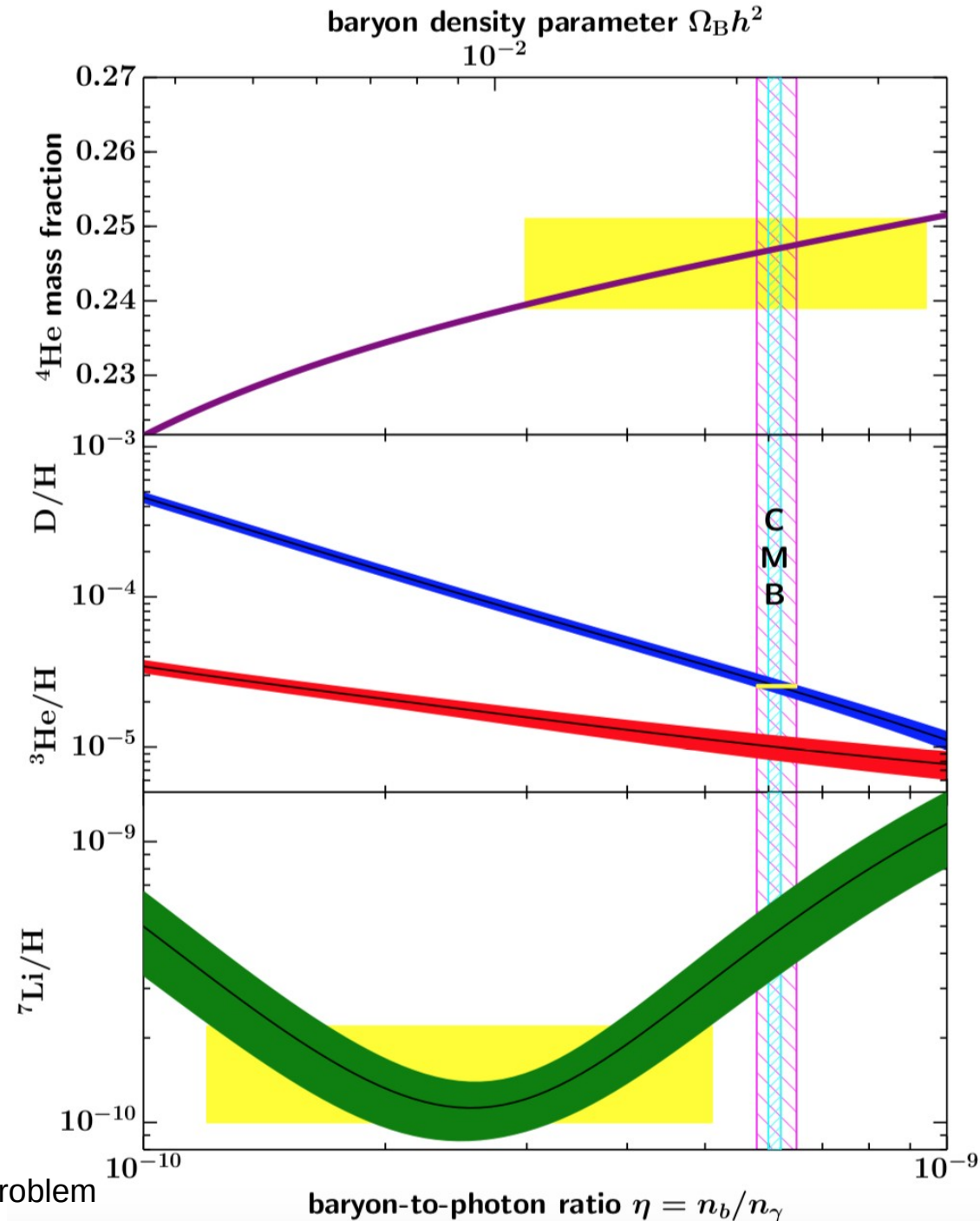
$$\eta_{\text{BBN}} = \eta_{\text{CMB}} = \eta_{\text{today}}$$



CLiP – nuclear PoV

Theory:

- 1 free parameter η
- 4 predicted abundances



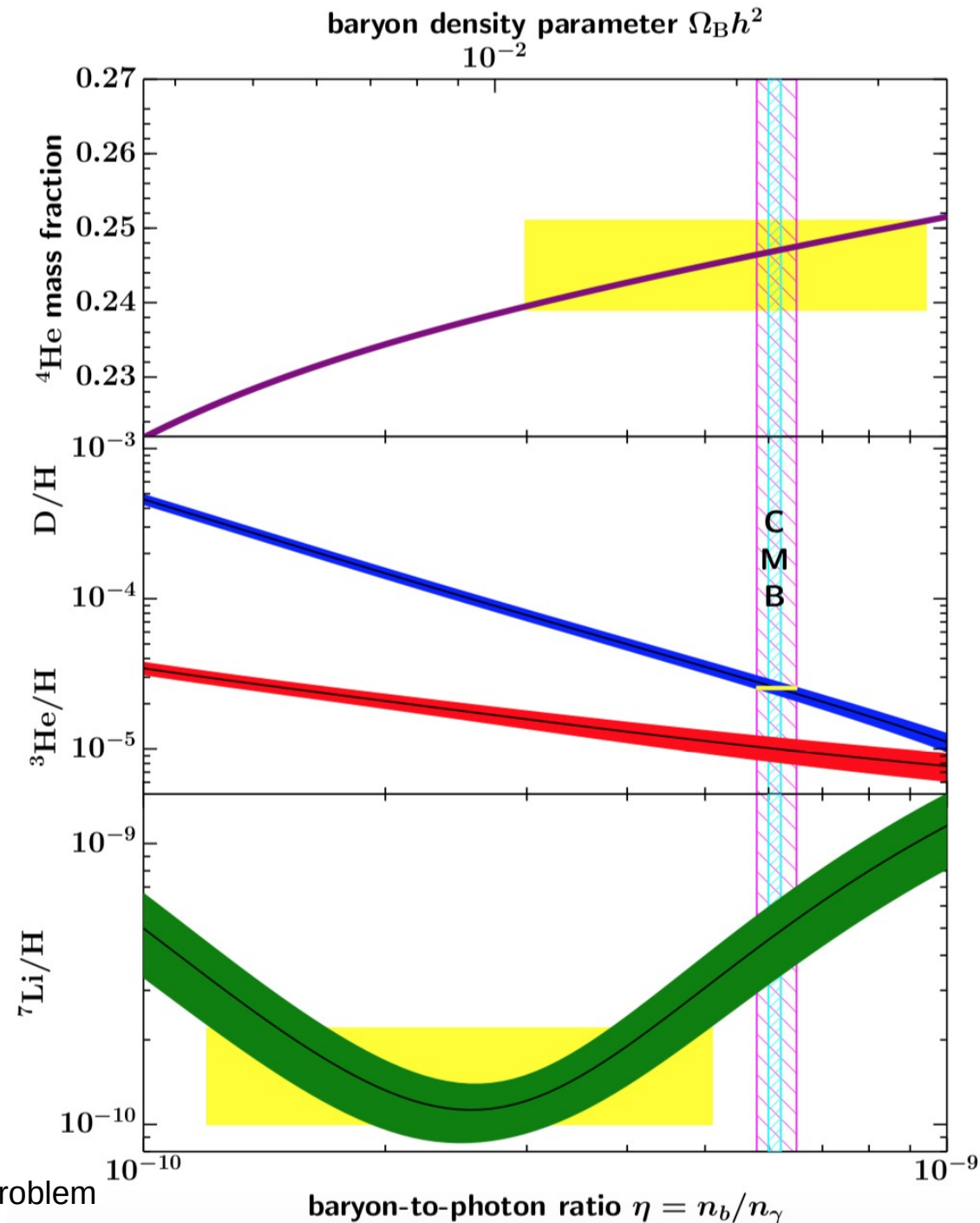
CLiP – nuclear PoV

Theory:

- 1 free parameter η
- 4 predicted abundances

Observations:

- 3 measured abundances
- rough agreement
- tension D vs ${}^7\text{Li}$



CLiP – nuclear PoV

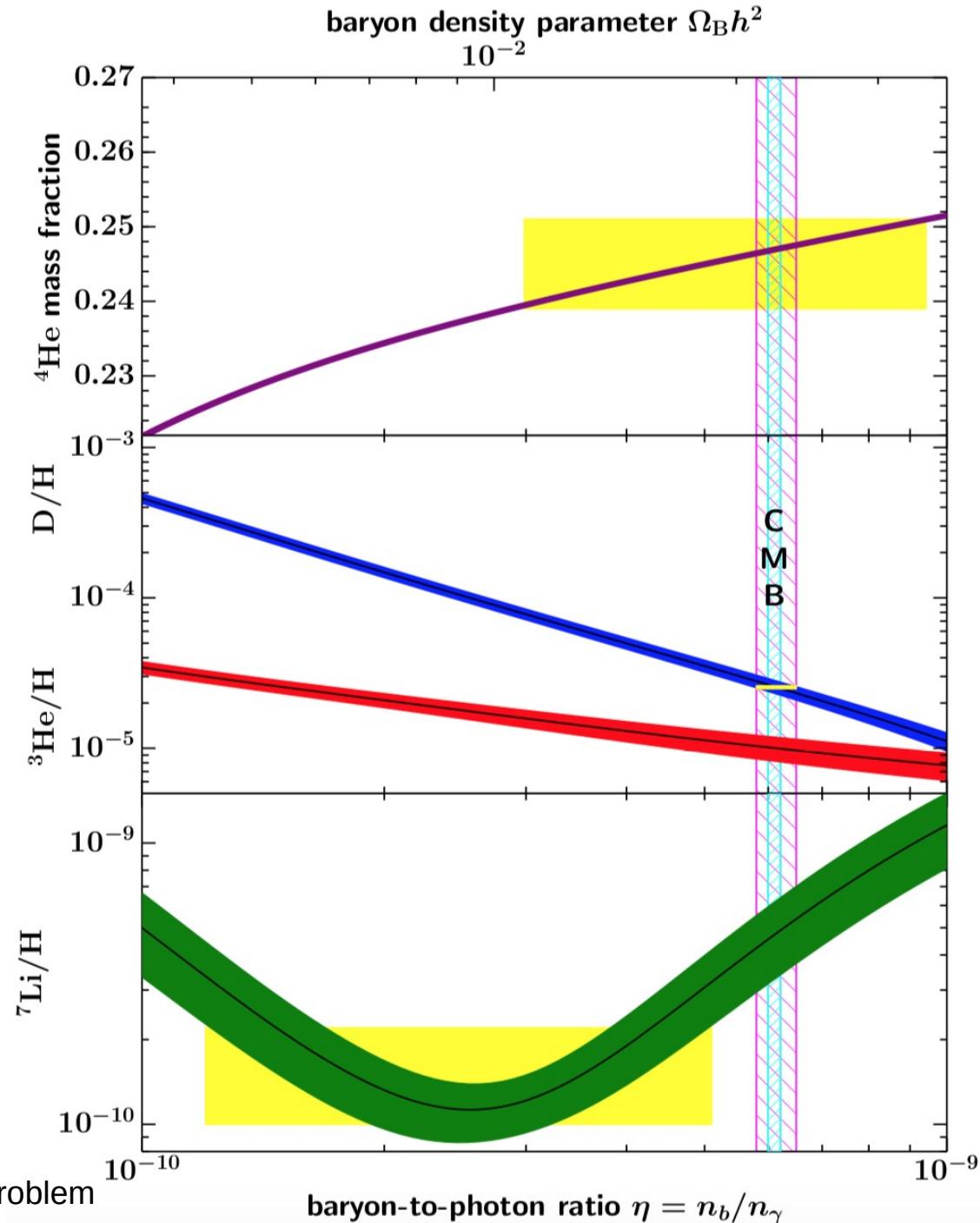
Theory:

- 1 free parameter η
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? Solution – change
colored bands !



CLiP – nuclear PoV

Theory:

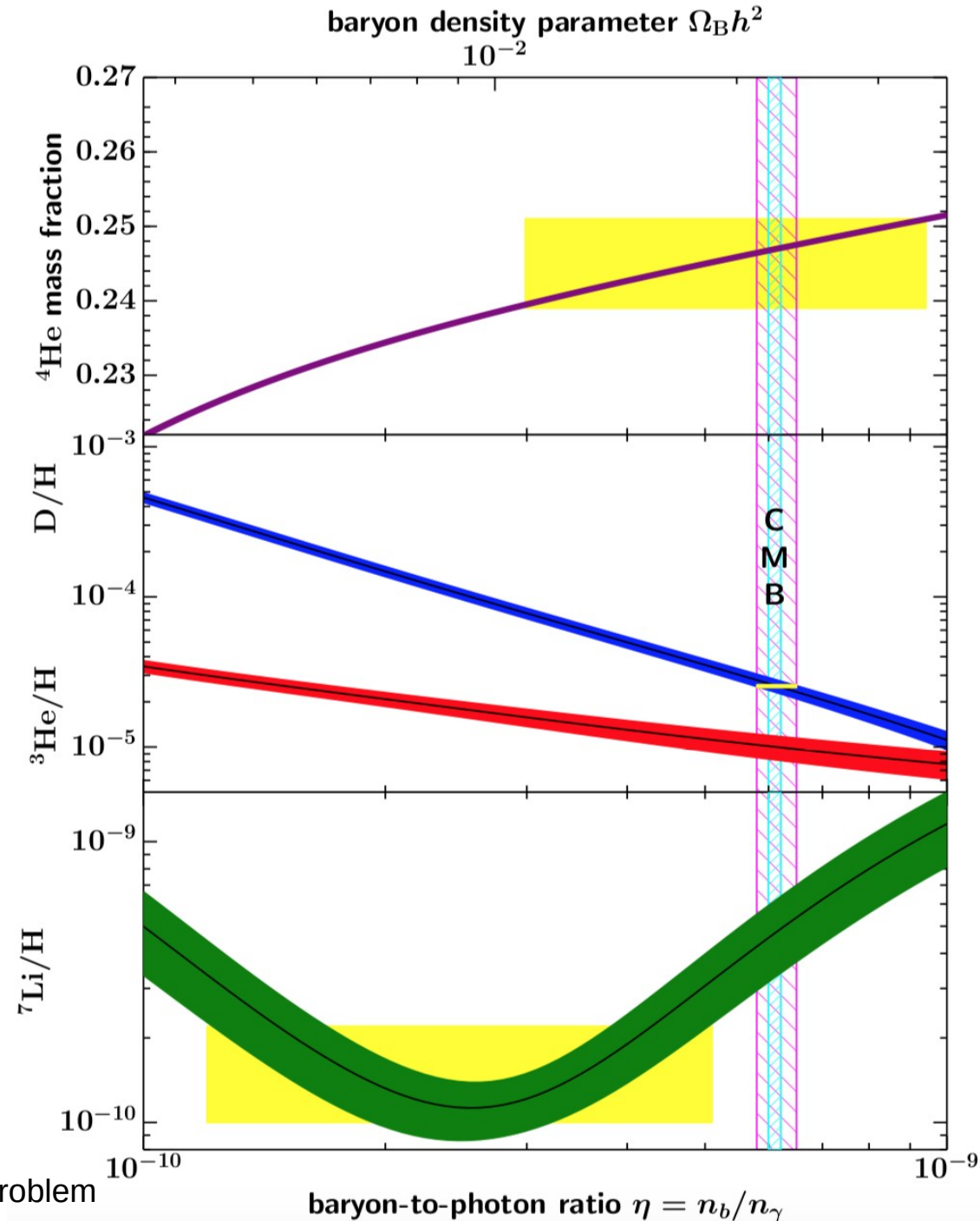
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!!! Independent measure of η
!!! CMB !!!



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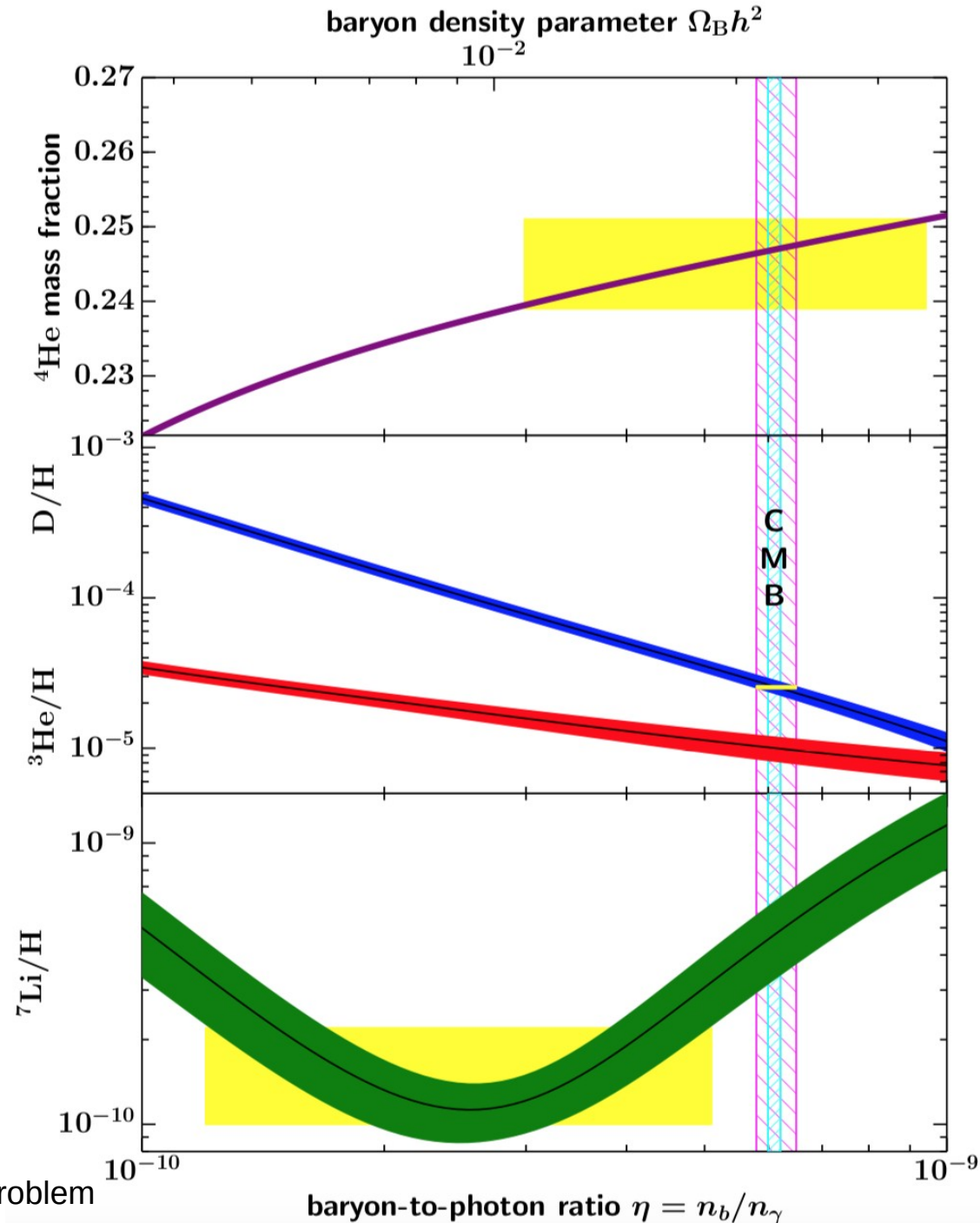
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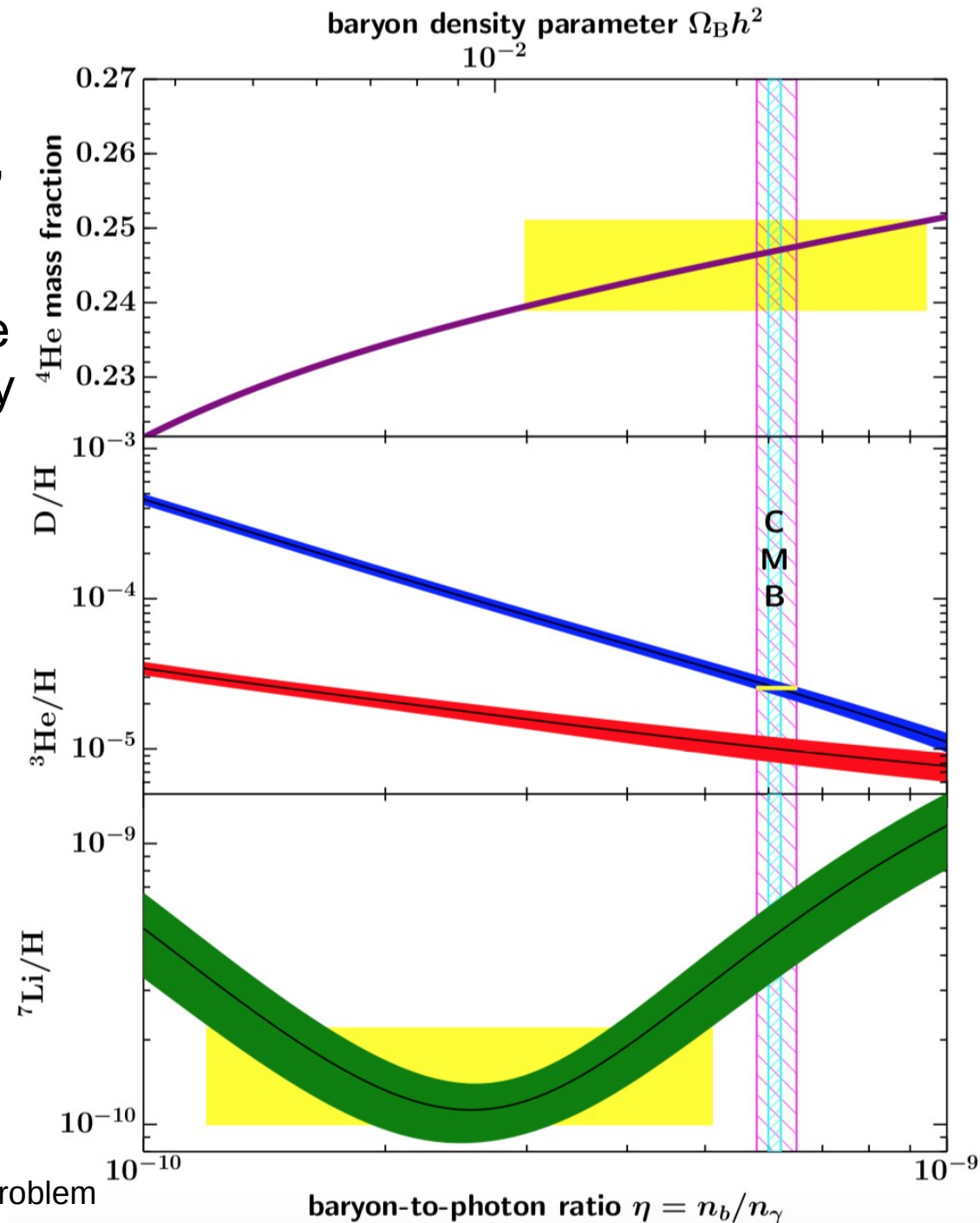
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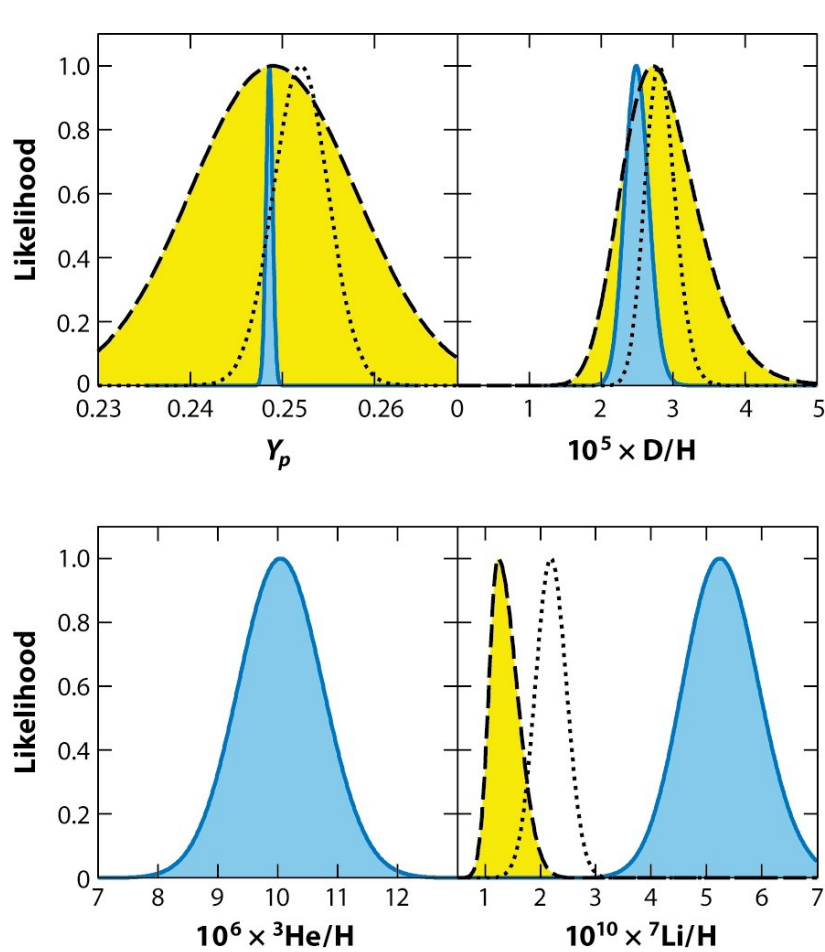
[PDG, Phys. Rev. D 98, 030001 (2018)]

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[n_TOF Coll. PRL 117, 152701 (2016)]



Cosmological Lithium Problem

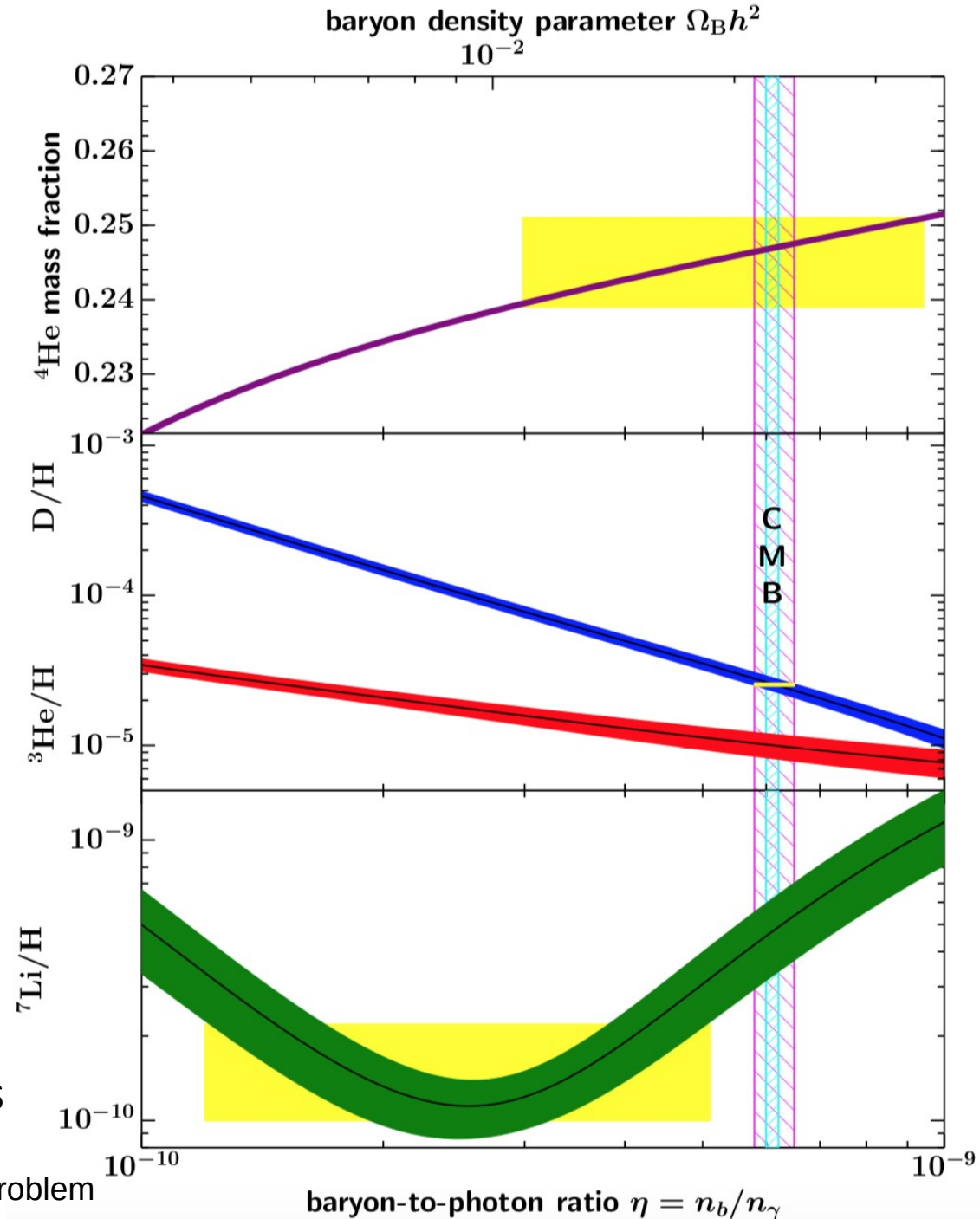


Fields BD. 2011.

Annu Rev. Nucl. Part. Sci. 61:47–68

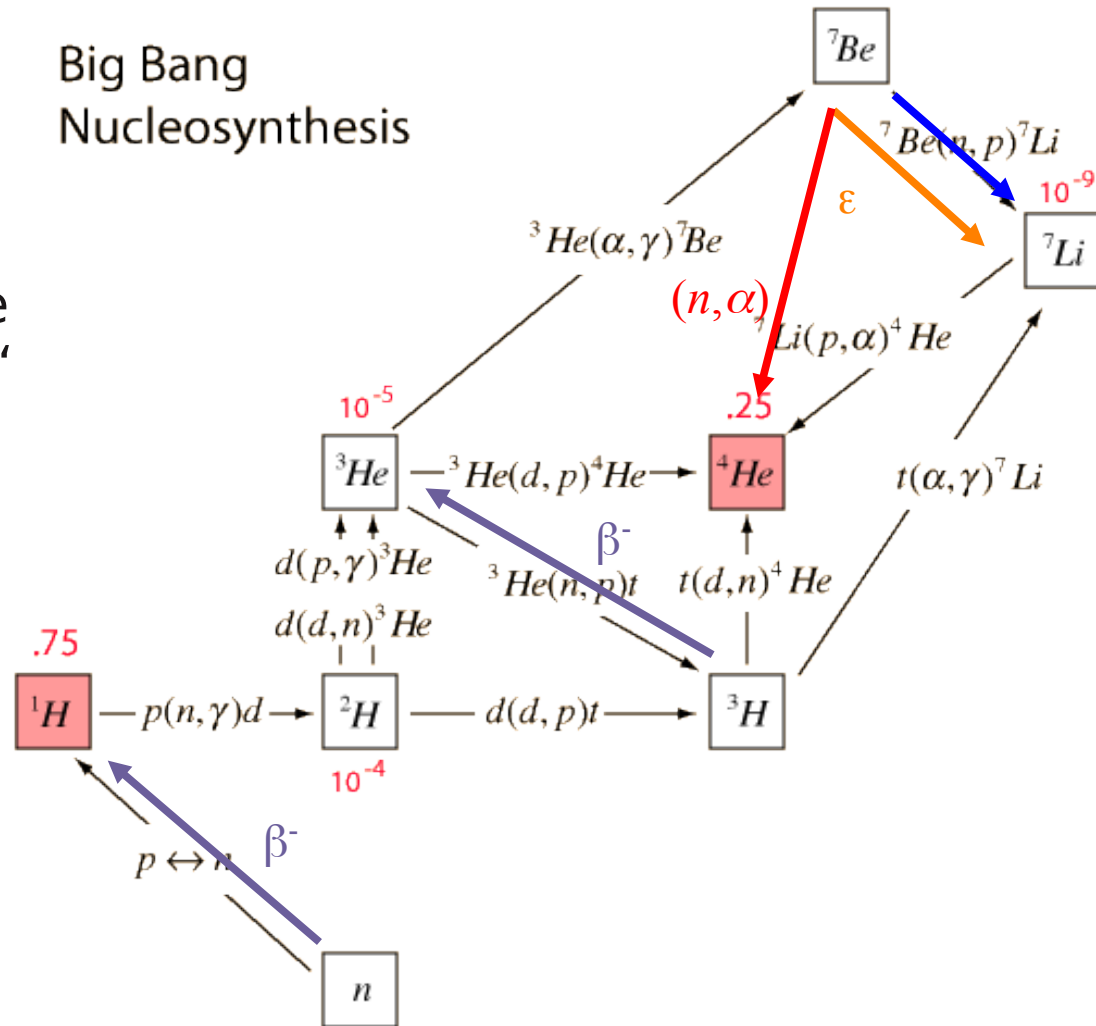
light blue is BBN with CMB η

yellow and dotted are measurements



Nuclear solution to CLiP?

- **Other path during BBN?**
„A cross section for the (n, α) reaction 2 orders of magnitude higher than currently used in BBN calculations, in the pertinent neutron energy region, could solve the cosmological lithium problem.“
[n_TOF Coll. PRL 117, 152701 (2016)]
- **Different xs than used?**
„The ${}^7\text{Be}(n, p){}^7\text{Li}$ reaction is responsible for a dominant fraction of the destruction of ${}^7\text{Be}$ Despite its importance, very few direct measurements exist for this reaction.“
[n_TOF Coll. PRL 121, 042701 (2018)]
- neutron-induced reactions, yay, let's go to n_TOF!



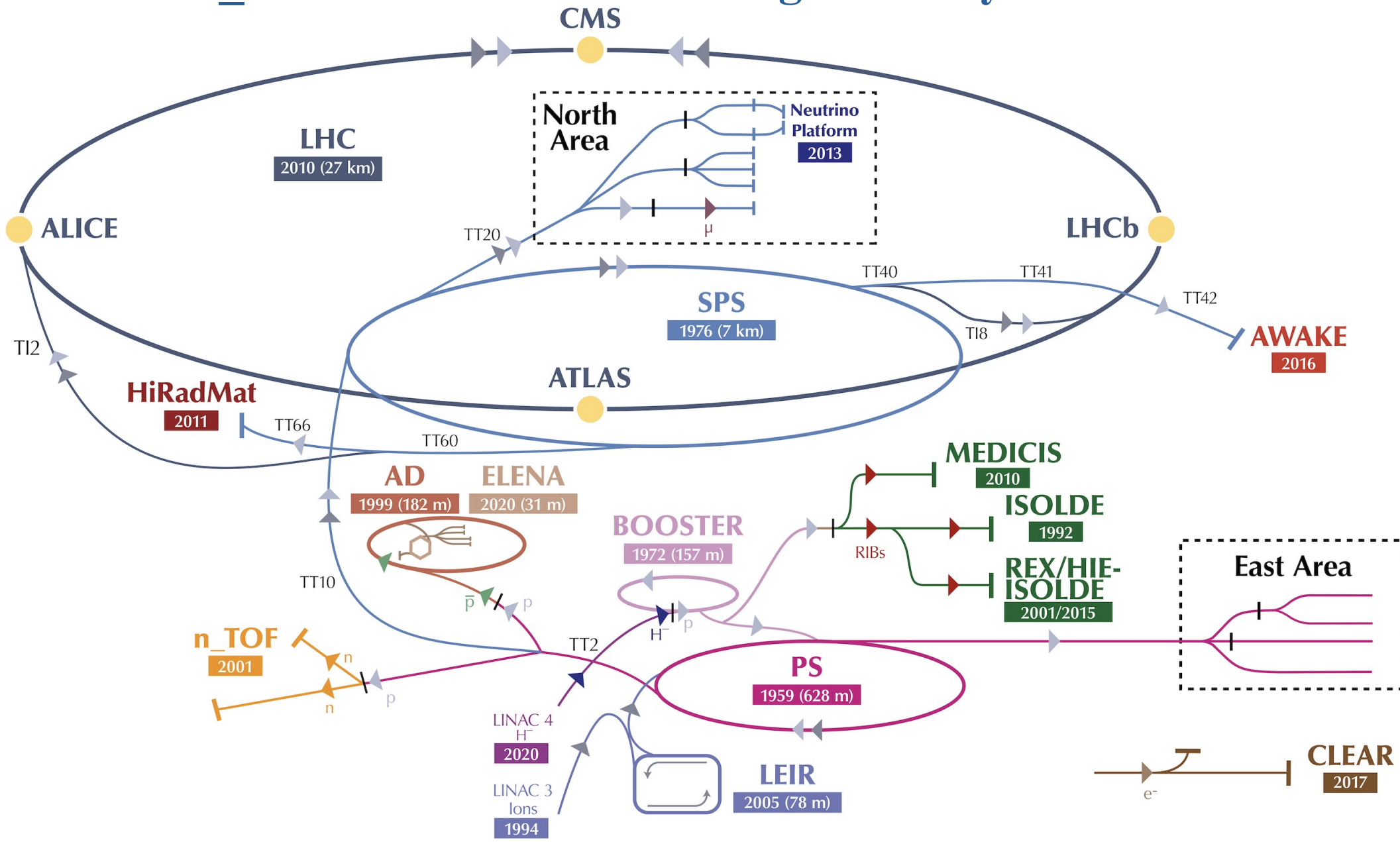
n_TOF

n_TOF = neutron time of flight facility at CERN

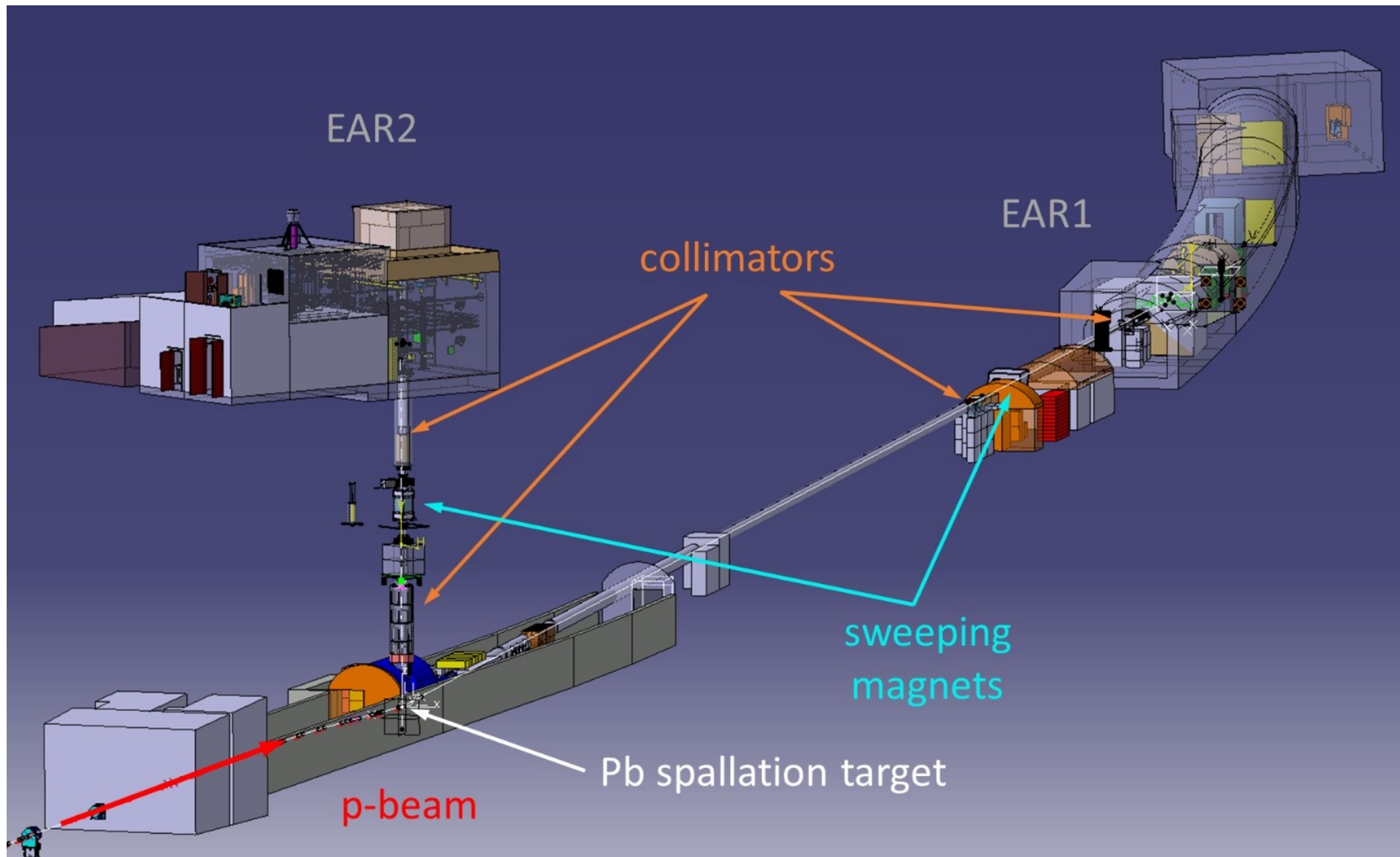


n_TOF

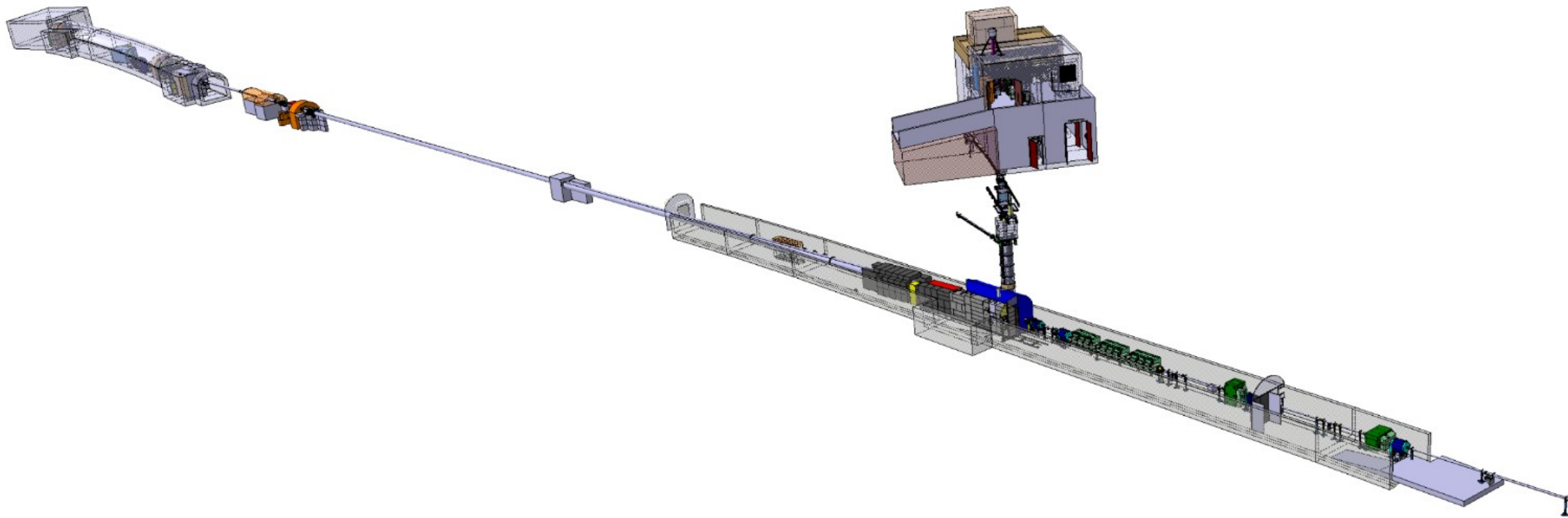
n_TOF = neutron time of flight facility at CERN



n_TOF



n_TOF



n_TOF



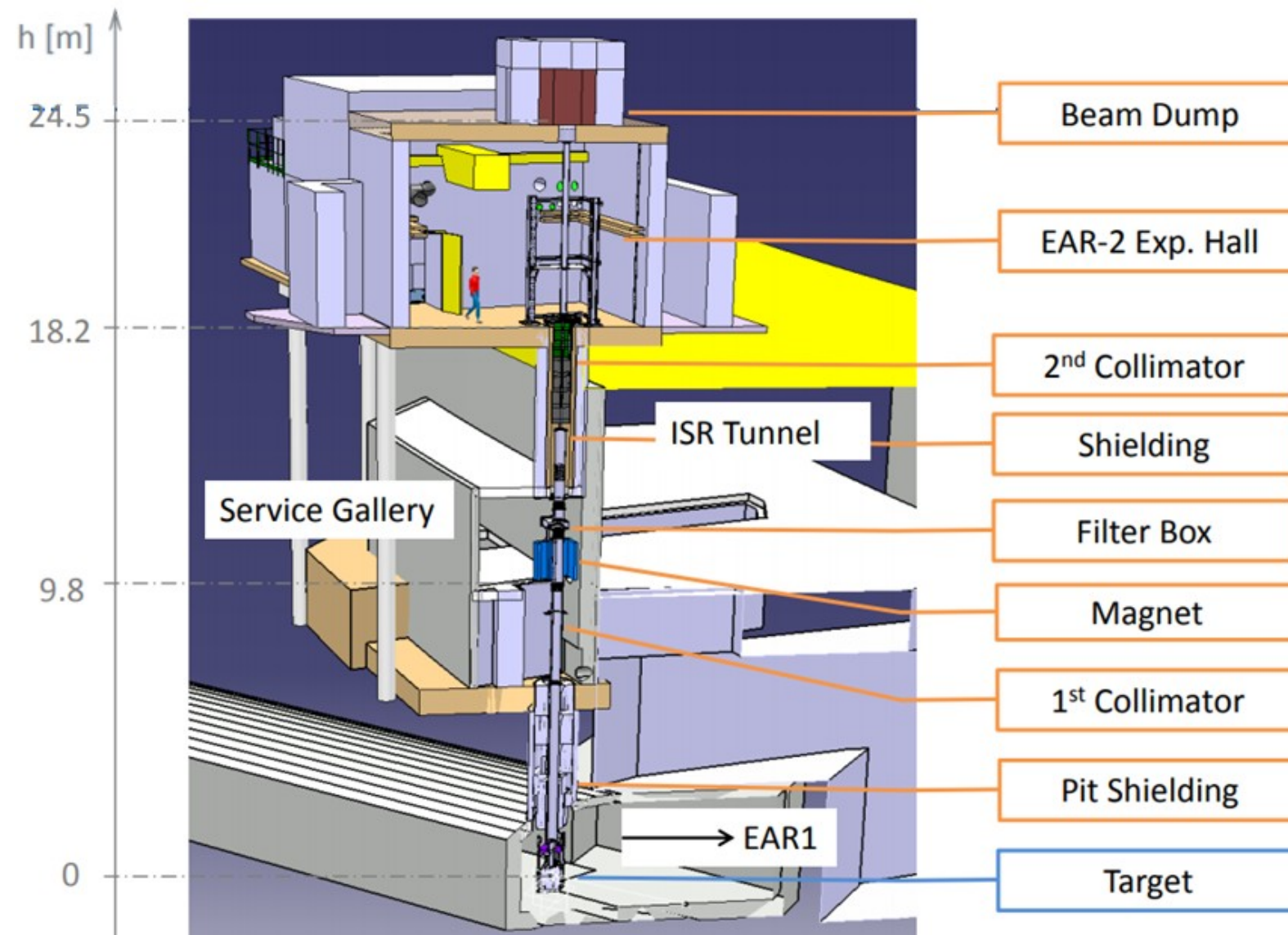
n_TOF



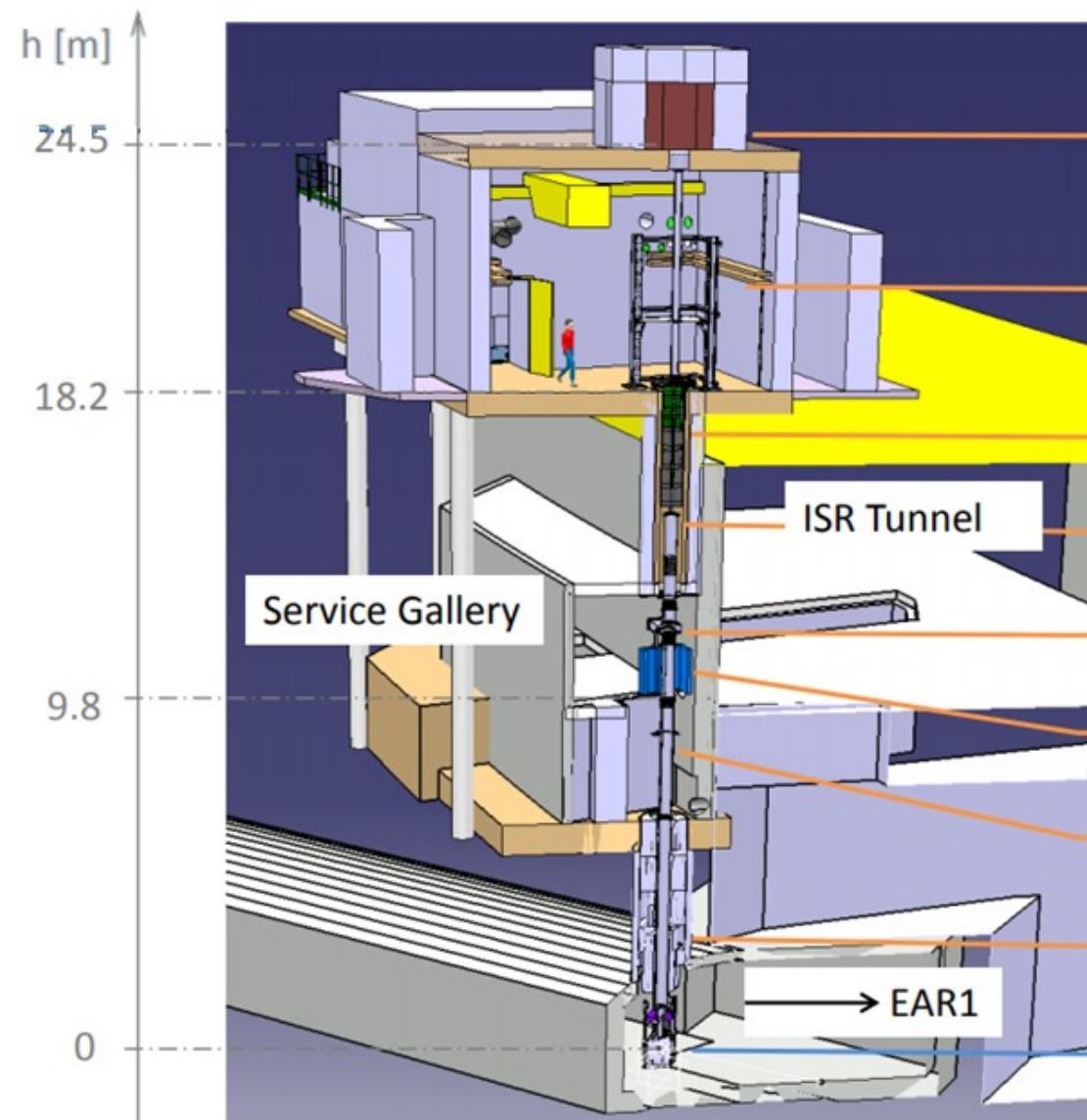
n_TOF



n_TOF – Target & EAR-2

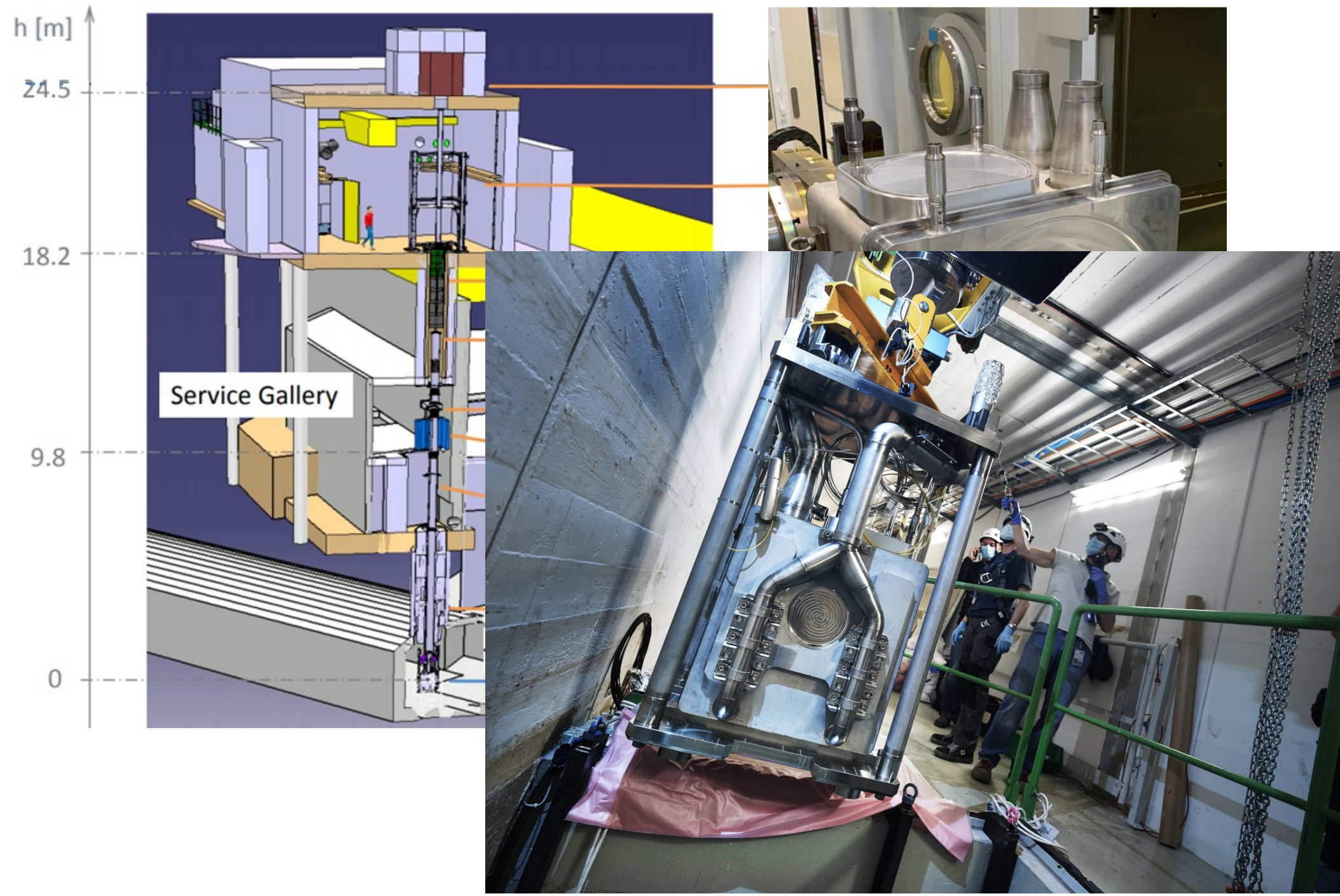


n_TOF - Target

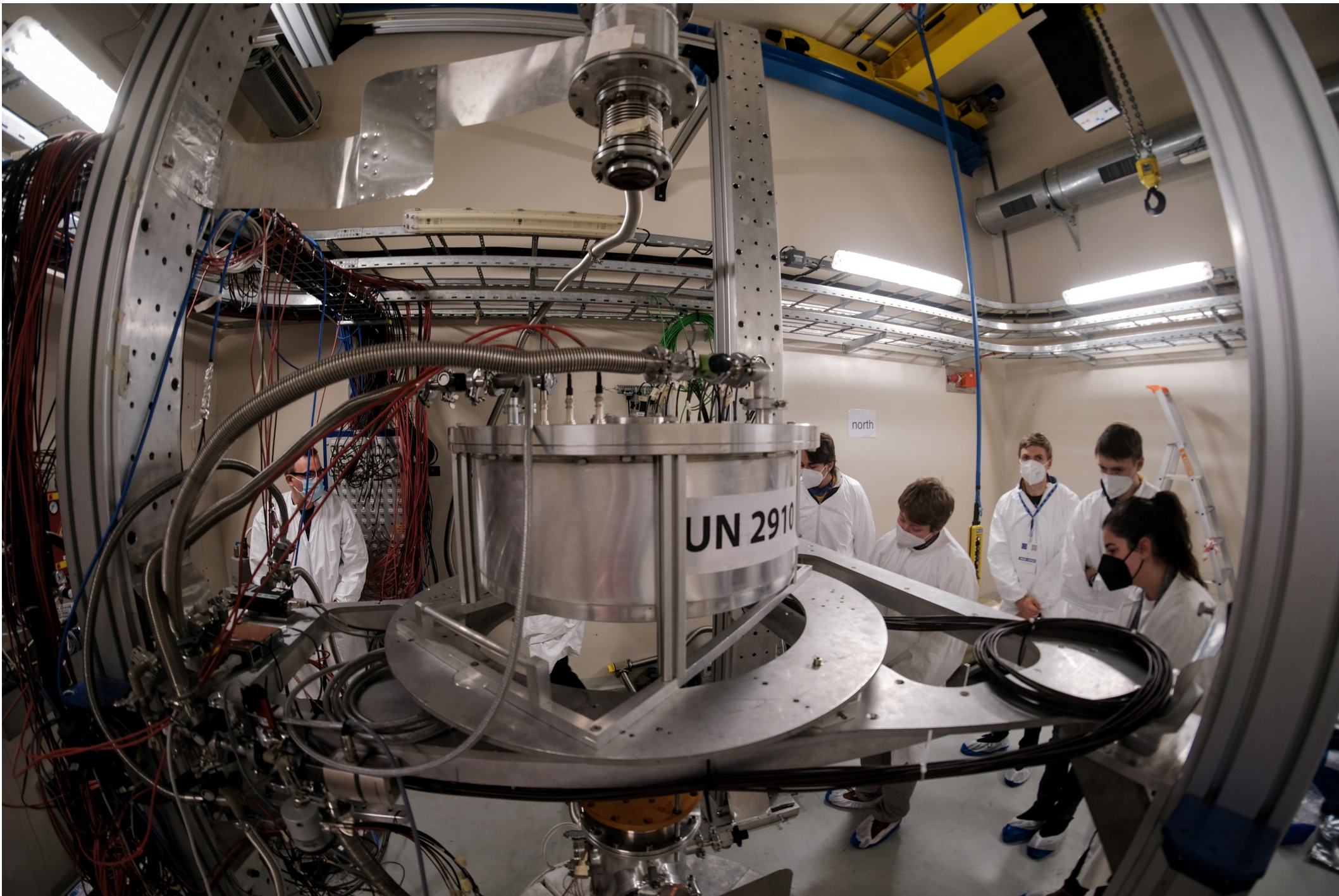


Target

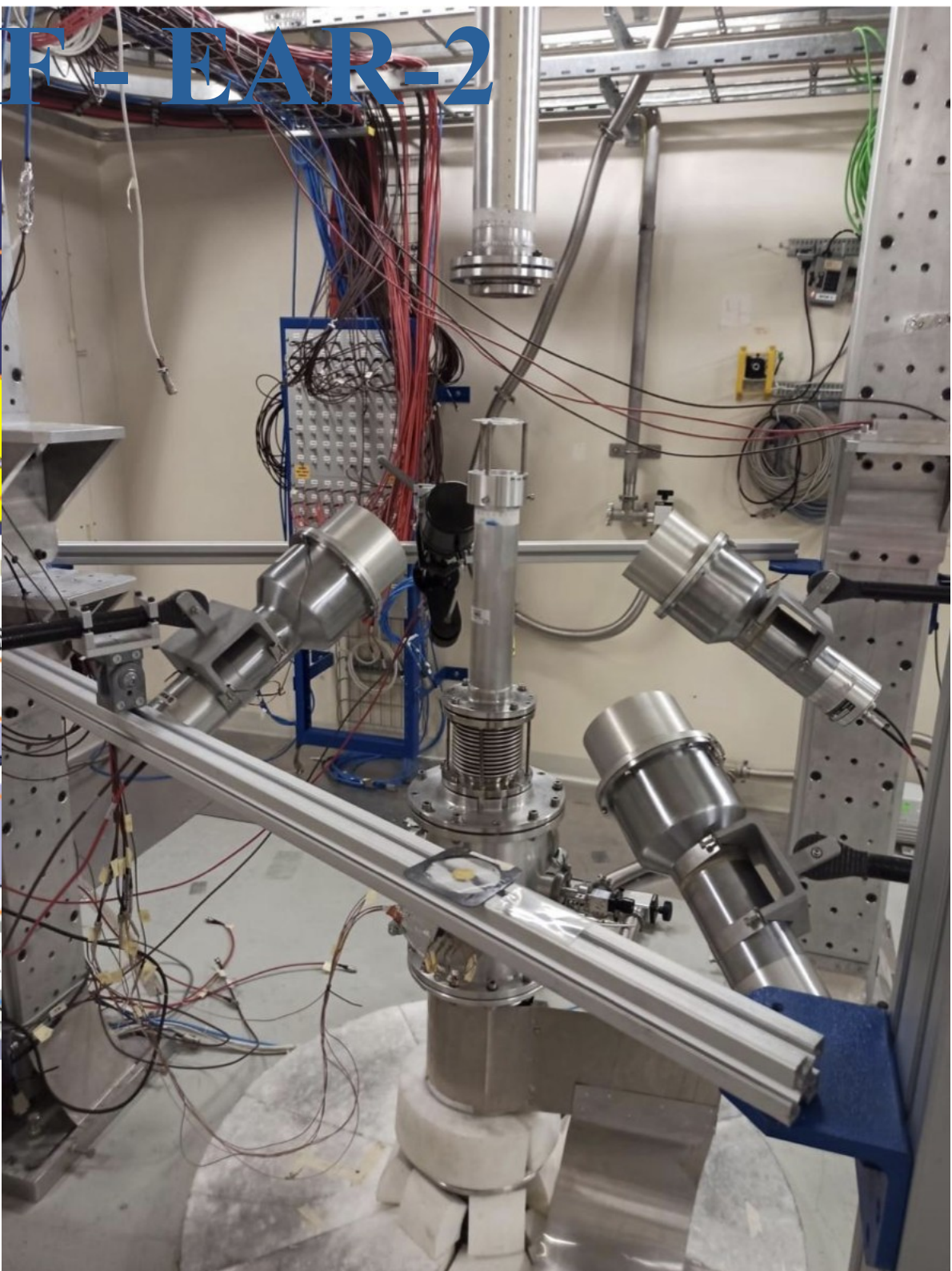
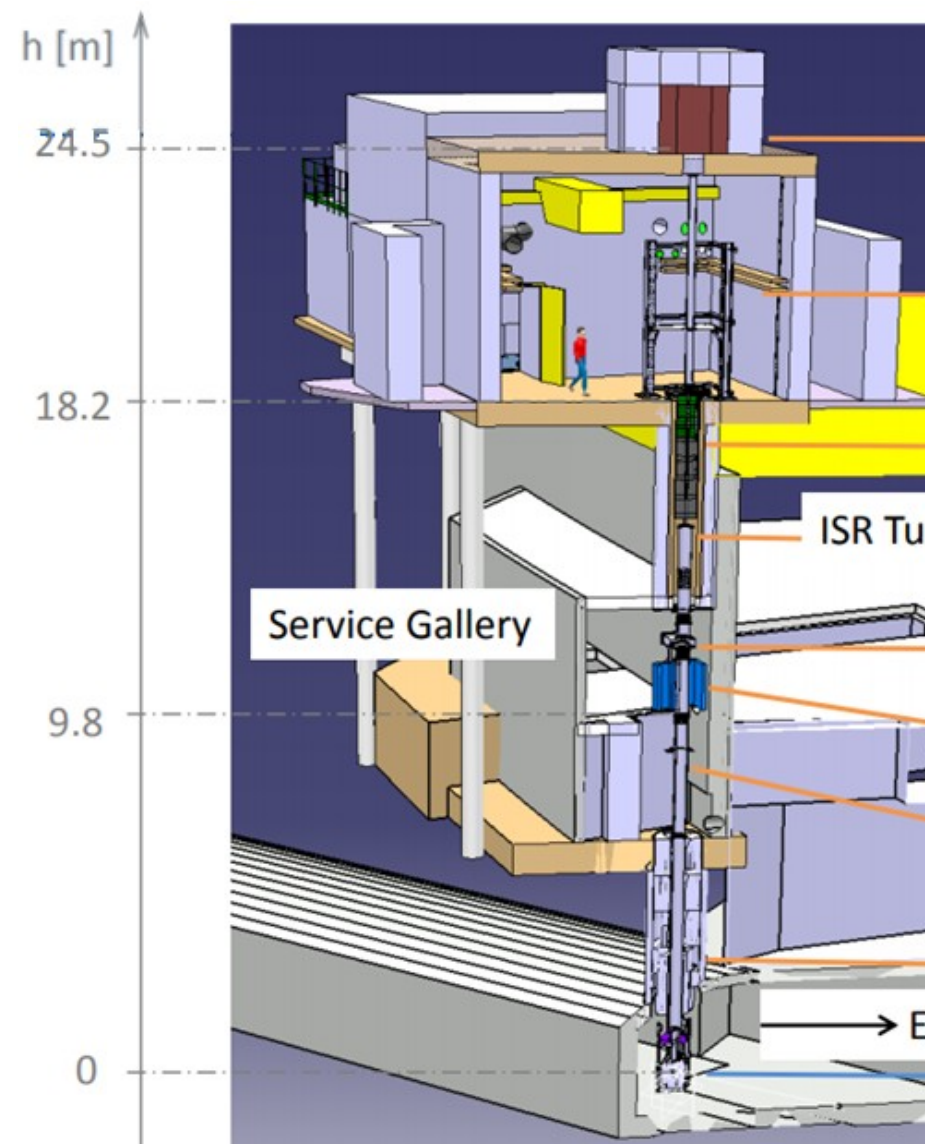
n_TOF - Target



n_TOF - EAR-2



n_TOF-EAR-2



Google + Wikipedia

- google „neutron time of flight“:

Google search results for "neutron time of flight".

Približne 6 720 000 výsledkov (0,46 sekundy)

The Neutron Time Of Flight (n-TOF) facility is a neutron spectrometer at CERN. It consists of a pulsed source, a flight path of 200 m length, and a detector systems. Neutron energies are deduced from the time of flight between source and detector; hence the name of the facility.

wikipedia.org
https://en.wikipedia.org/wiki/Neutron_Time_Of_Flight

Neutron Time Of Flight - Wikipedia

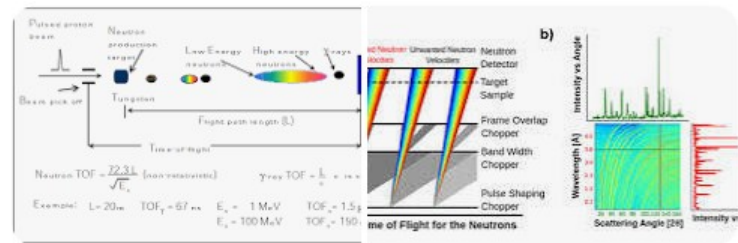
Podobné dopyty :

- How fast is a neutron?
- What is the relation between the neutron wavelength and the time of flight over a particular distance?
- What is the temperature of thermal neutron?

Spätňá väzba

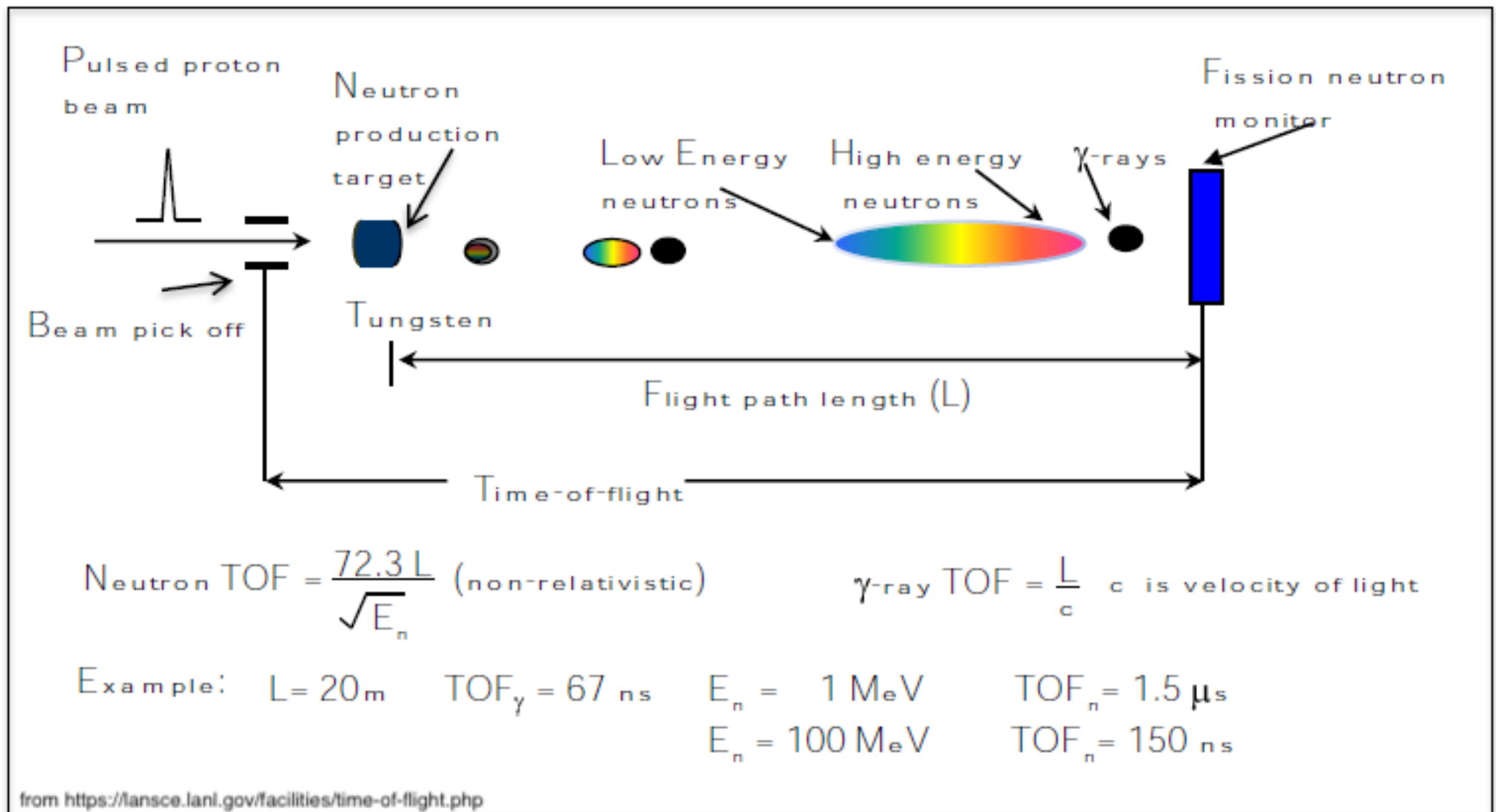
Neutron Time Of Flight

Preložené z angličtiny - Zariadenie Neutron Time Of Flight je neutrónový spektrometer v CERN-e. Pozostáva z impulzného zdroja, dráhy letu s dĺžkou 200 m a systému detektorov. Energie neutrónov sú odvodené z času letu medzi zdrojom a detektorom; odtiaľ názov zariadenia. Wikipédia (angličtina)



Google + Wikipedia

- google „neutron time of flight“ & switch to images



ChatGPT

? Imagine you are writing a wikipedia page about neutron time of flight, what would you write?

Neutron time of flight is a method used to measure the time taken by a neutron to travel from a source to a detector. This method is widely used in the field of nuclear physics, where it provides valuable information about the energy and **properties of neutrons**.

The neutron time of flight technique involves measuring the time taken by a neutron to travel from a source to a detector. This time is then used to determine the energy of the neutron, based on the relationship between energy and velocity.

The basic principle behind neutron time of flight is that neutrons of different energies travel at different velocities. By measuring the time taken by a neutron to travel a known distance, it is possible to determine the velocity and hence the energy of the neutron.

The neutron time of flight technique is typically used in conjunction with a neutron source and a detector. The neutron source is usually a target that is bombarded with high-energy particles, such as protons or alpha particles, to produce neutrons. The neutrons are then directed towards the detector, which is typically a scintillator or a neutron-sensitive film.

To measure the time taken by the neutron to travel from the source to the detector, a timing system is used. **This typically consists of two or more neutron detectors placed at known distances from the neutron source.** The detectors are designed to detect the arrival of the neutron and to record the time at which it arrives.

By comparing the time taken by the neutron to travel between the different detectors, it is possible to determine the velocity of the neutron and hence its energy. This information can be used to study a wide range of phenomena in nuclear physics, such as neutron scattering, nuclear reactions, and fission.

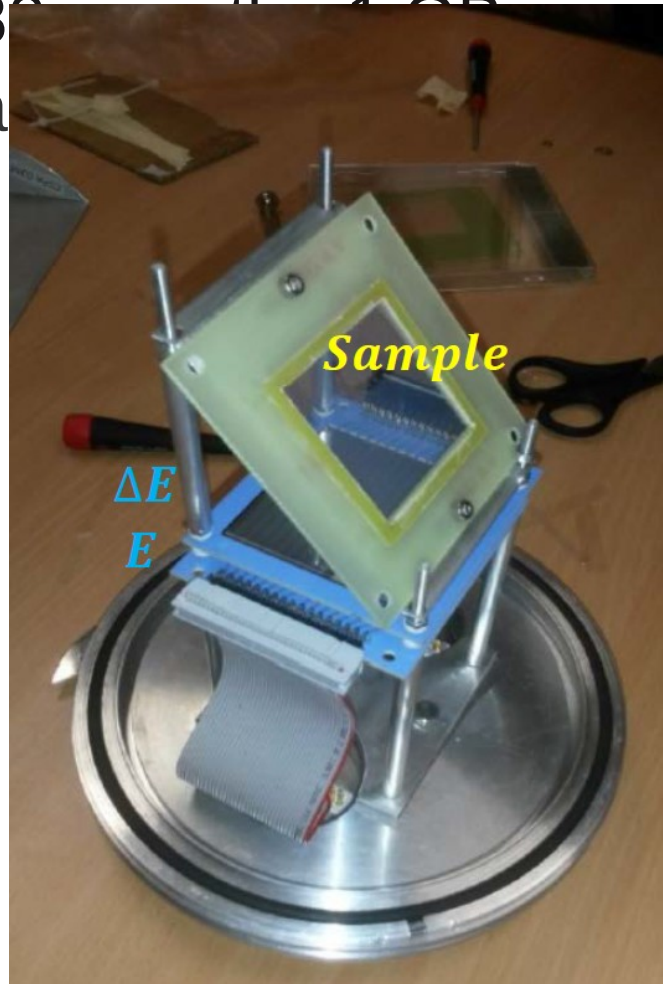
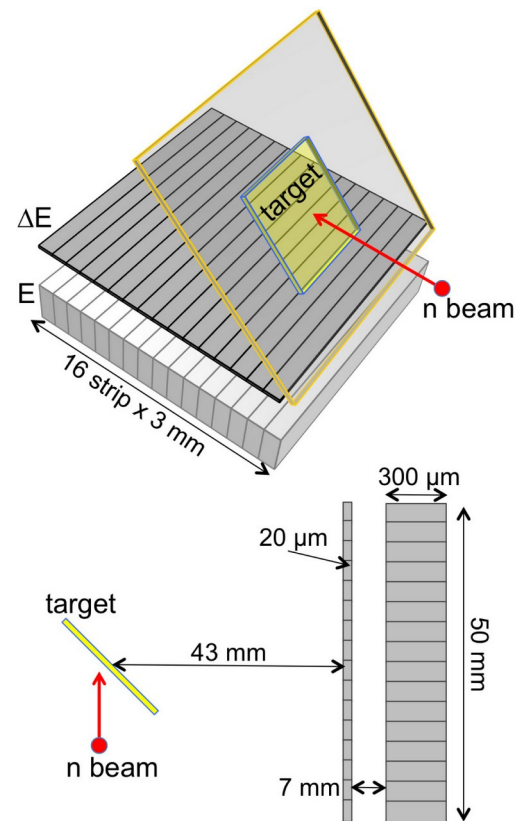
In conclusion, neutron time of flight is a valuable technique used in nuclear physics to measure the energy and properties of neutrons. It involves measuring the time taken by a neutron to travel from a source to a detector and can provide important information about a wide range of phenomena in the field of nuclear physics.

n_TOF – ^7Be measurements

- (n,α) possible for the first time thanks to the flux at EAR-2
- huge effort to make the samples – PSI+ISOLDE
- **very high activity of ^7Be material $\sim 13 \text{ GBq}/\mu\text{g}$**
- (n,α) sample $\approx 1.4 \mu\text{g}$ with $\sim 18 \text{ GBq}$
- (n,p) sample $\approx 80 \text{ ng}$ with $\sim 1 \text{ GBq}$
- each target measured for a period of ~ 45 days

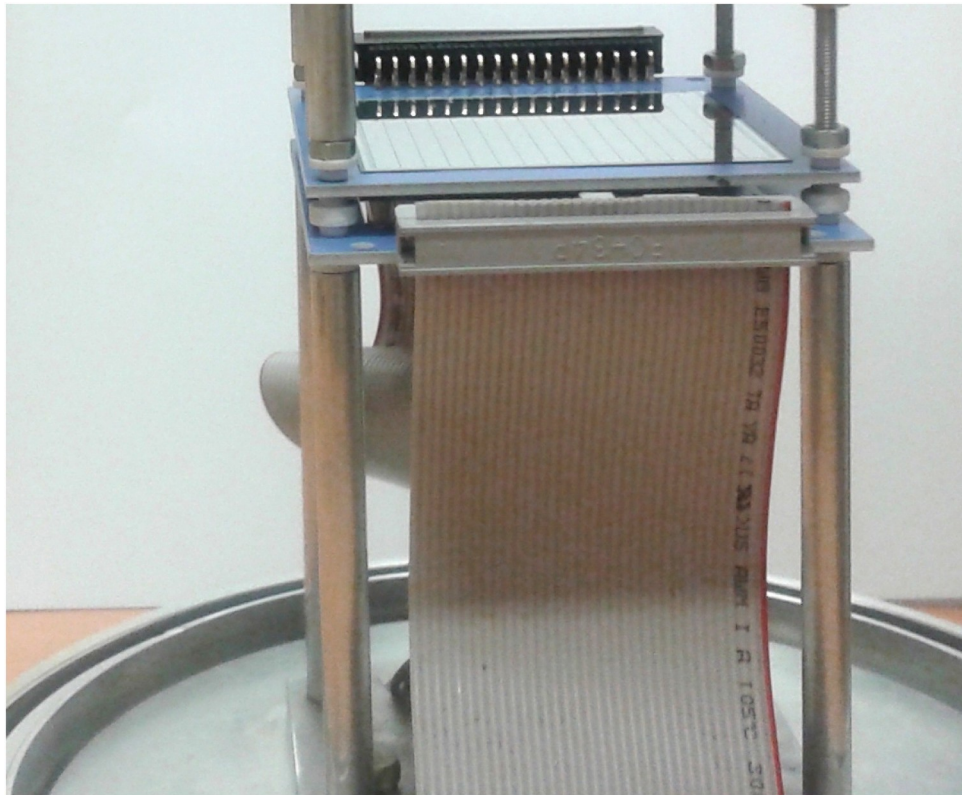
n_TOF – ^7Be measurements

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- (n,p) sample $\approx 8 \mu\text{g}$ with $\sim 1 \text{ GBq}$
- each target mea

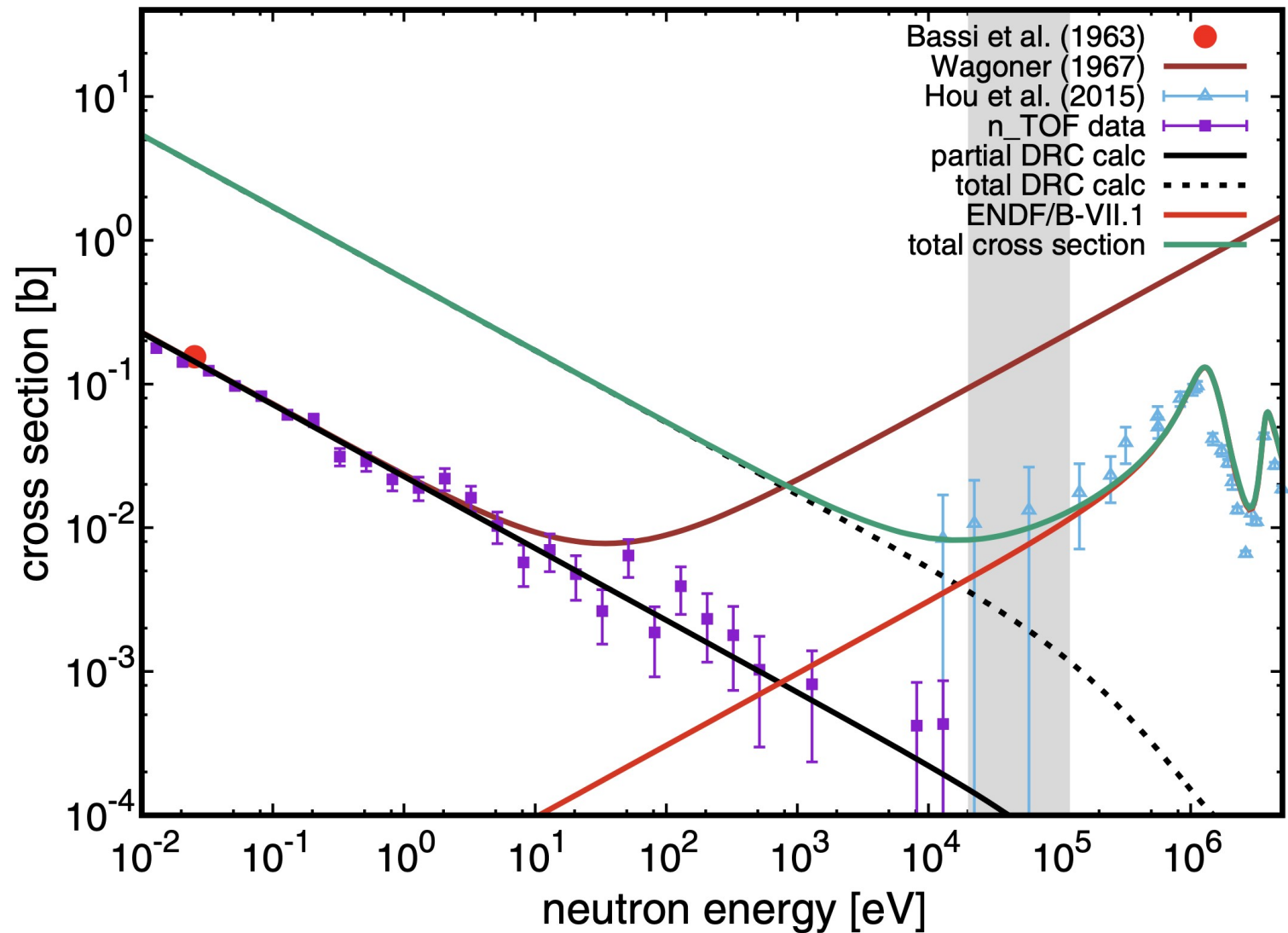


n_TOF – ^7Be measurements

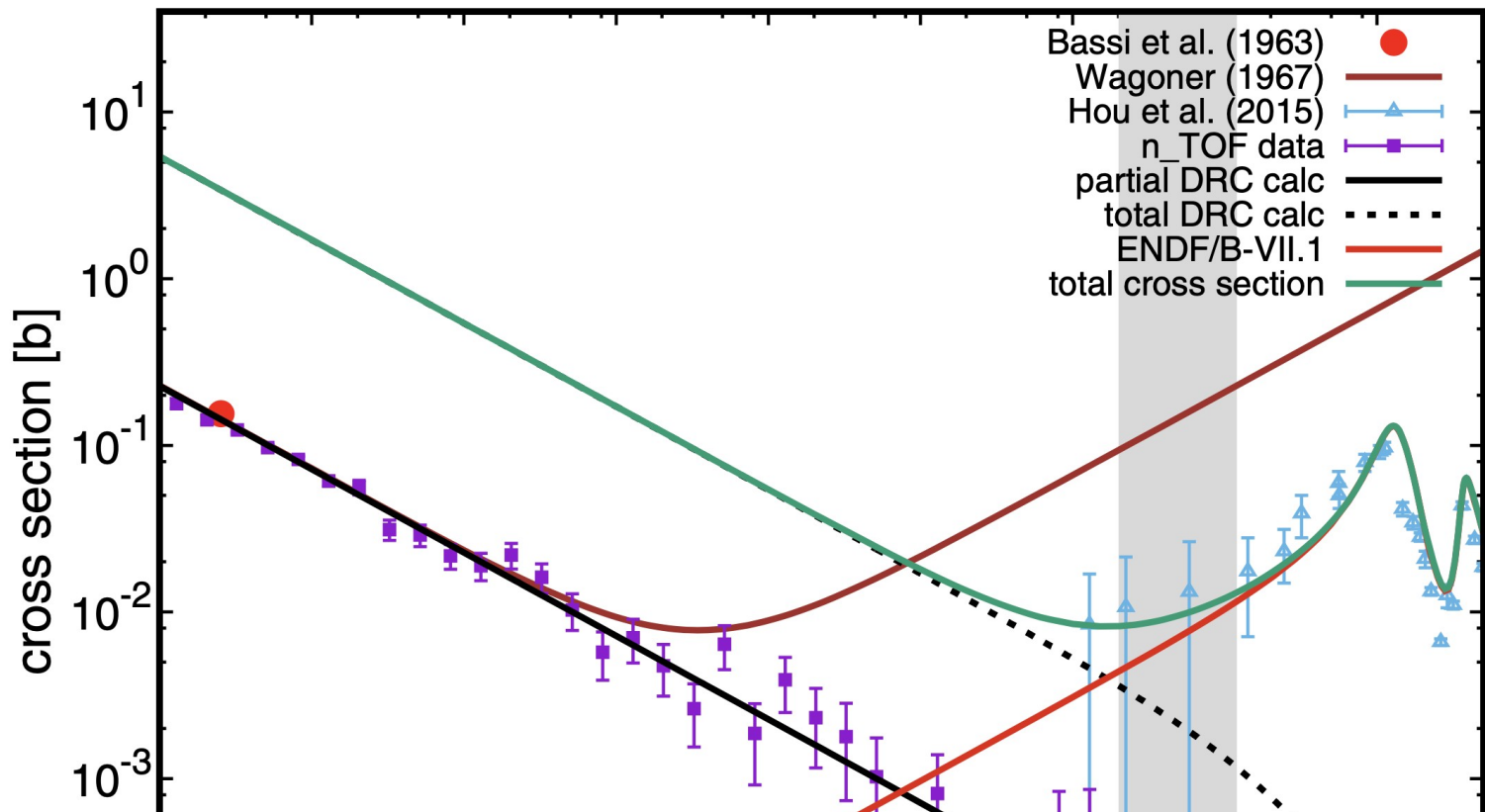
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n_TOF – $^7\text{Be}(n,\alpha)$ results

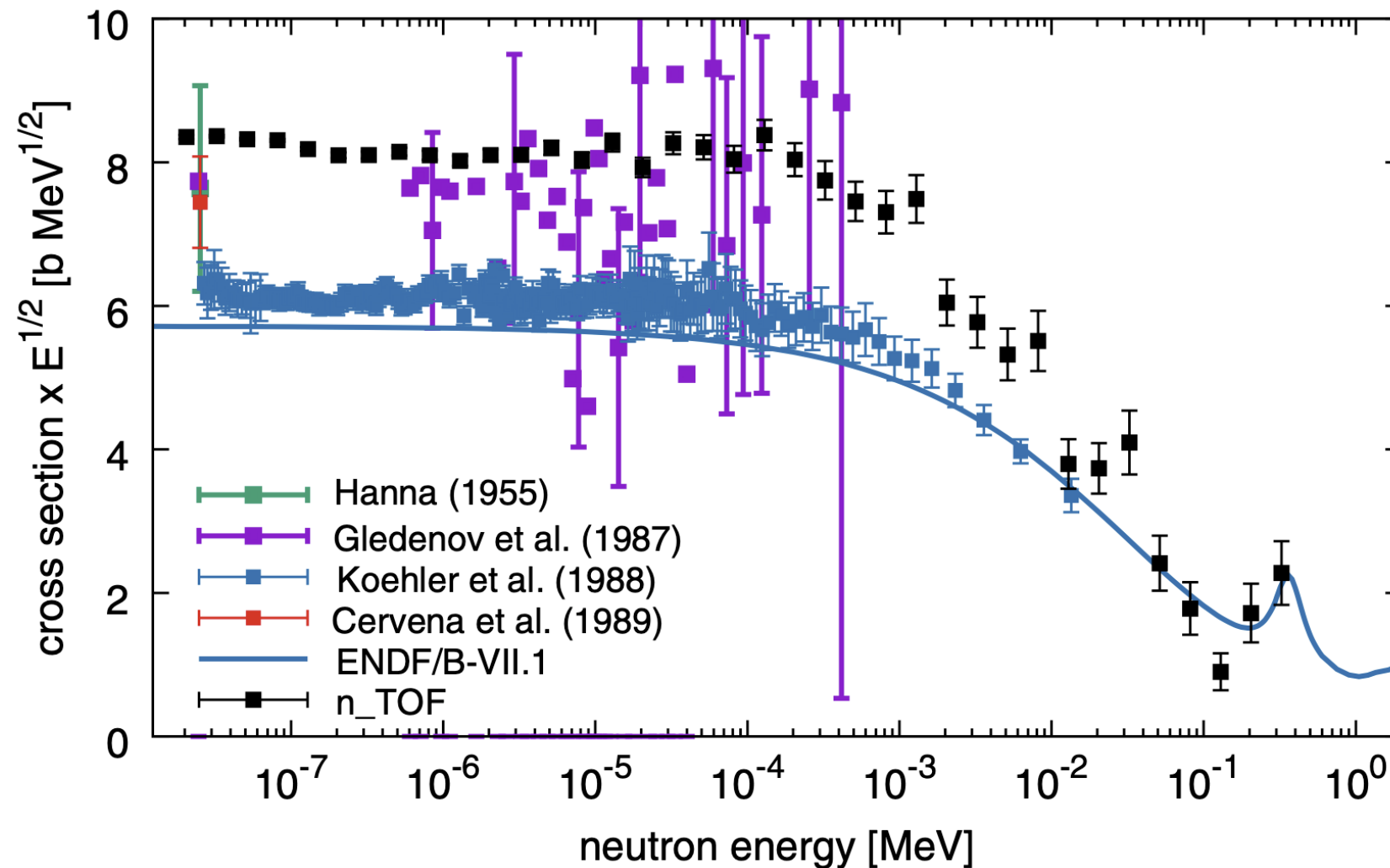


n_TOF – ${}^7\text{Be}(n,\alpha)$ conclusions

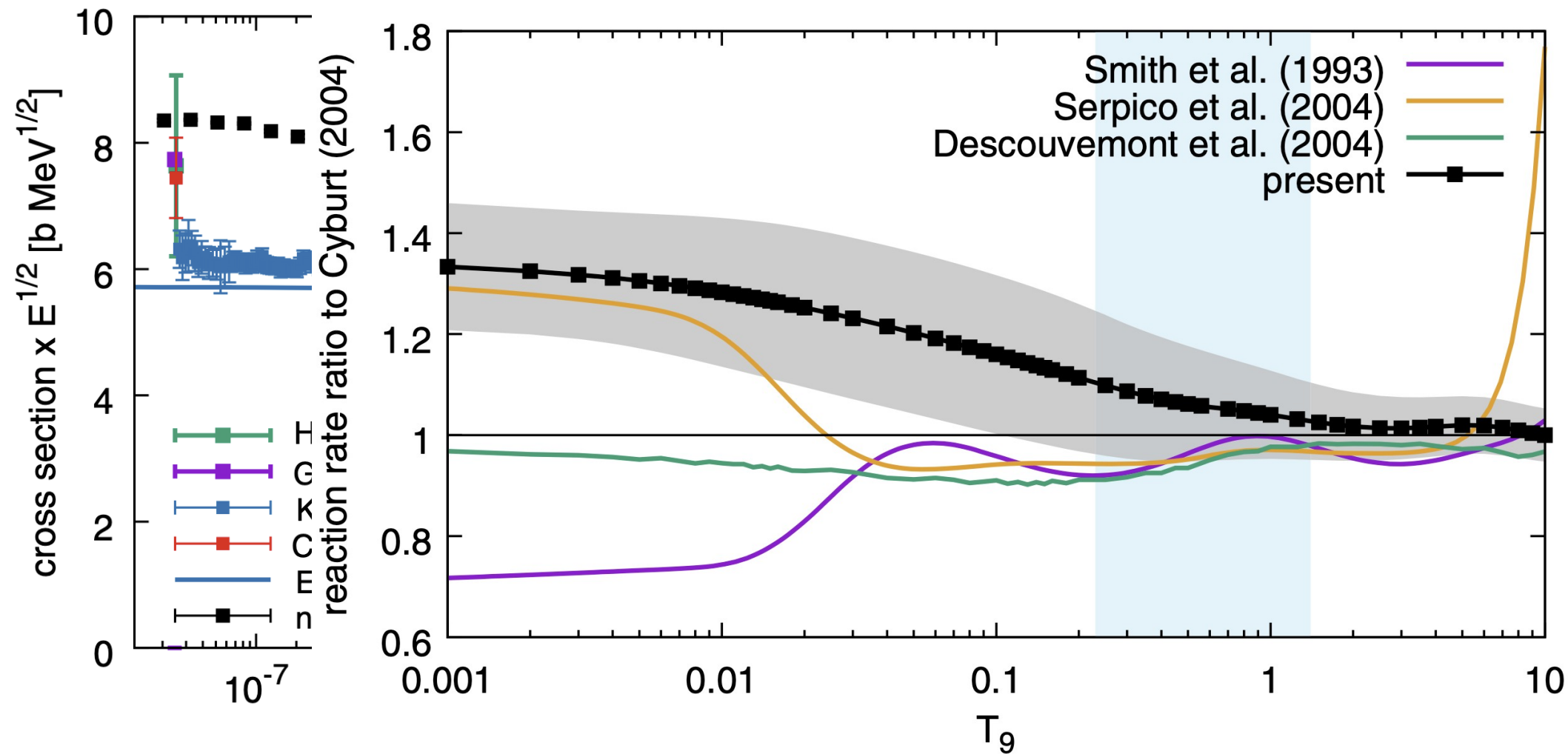


Considering that, as mentioned in the introduction, a factor of **100** or more **enhancement** in the ${}^7\text{Be}(n,\alpha)$ rate would be necessary to reconcile the standard BBN lithium yield with astrophysical observations, the presently established rate **10 times lower** than used so far in BBN calculations, leads to a **minor change** of the lithium yield, thus leaving the solution of the cosmological lithium problem to other alternative physical scenarios.

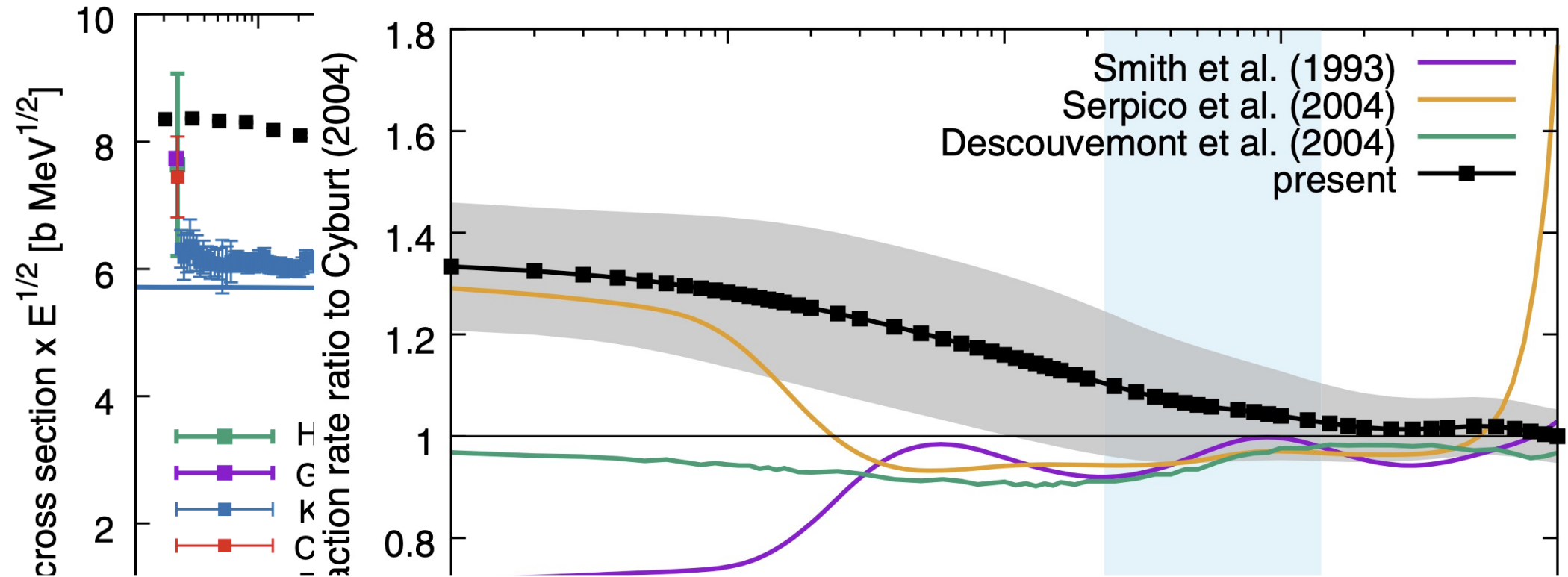
n_TOF – $^7\text{Be}(n,p)$ results



n_TOF – ${}^7\text{Be}(n,p) \rightarrow \text{BBN}$

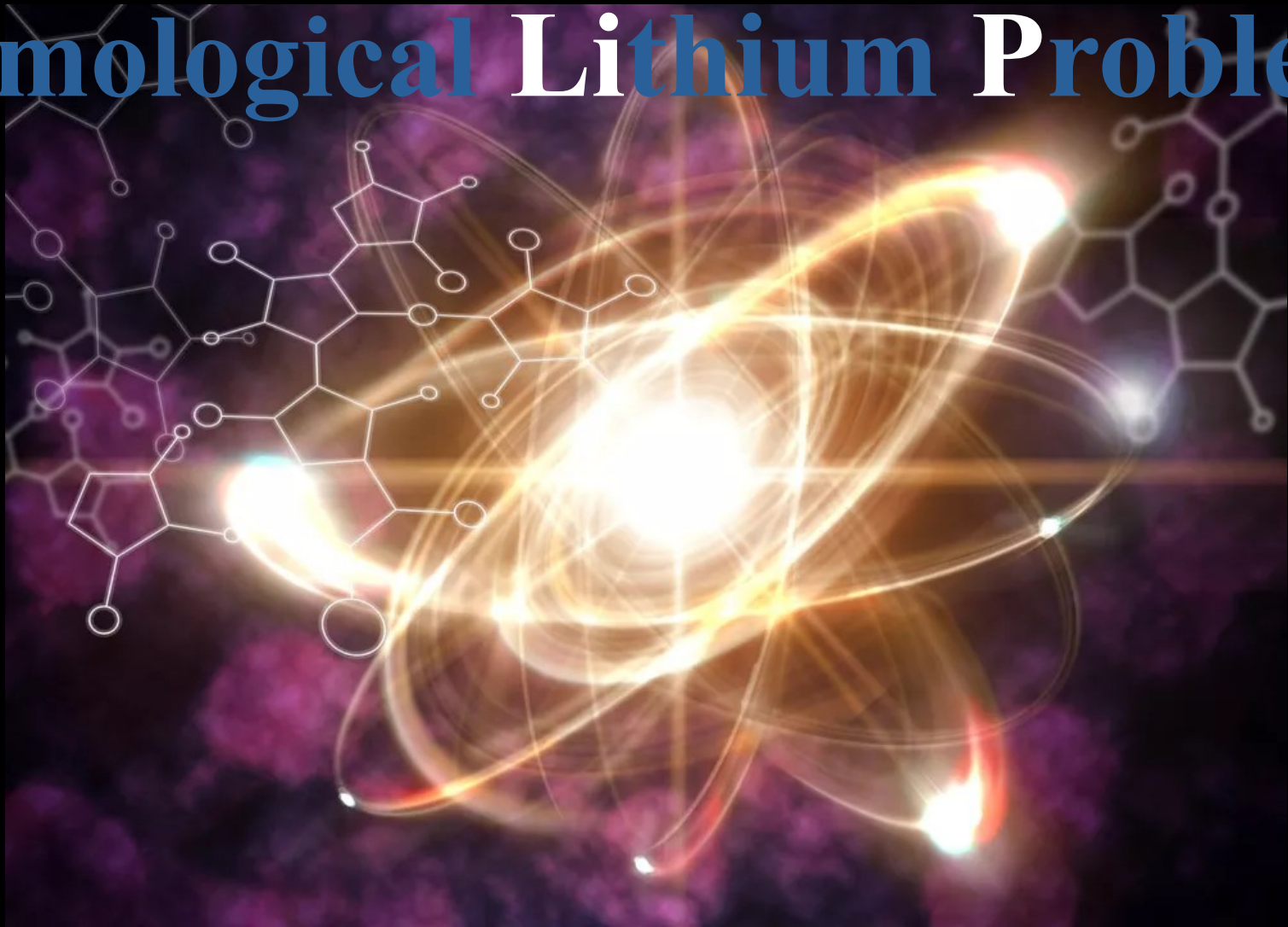


n_TOF – ${}^7\text{Be}(n,p)$ conclusions



The new estimate of the ${}^7\text{Be}$ destruction rate based on the new results **yields a decrease** of the predicted cosmological **lithium abundance** of $\sim 10\%$, **insufficient to provide** a viable **solution** to the cosmological lithium problem. The two n_TOF measurements of ${}^7\text{Be}(n,\alpha)$ and ${}^7\text{Be}(n,p)$ cross sections can finally rule out neutron-induced reactions, and possibly nuclear physics, as a potential explanation of the CLiP, leaving all alternative physics and astronomical scenarios still open.

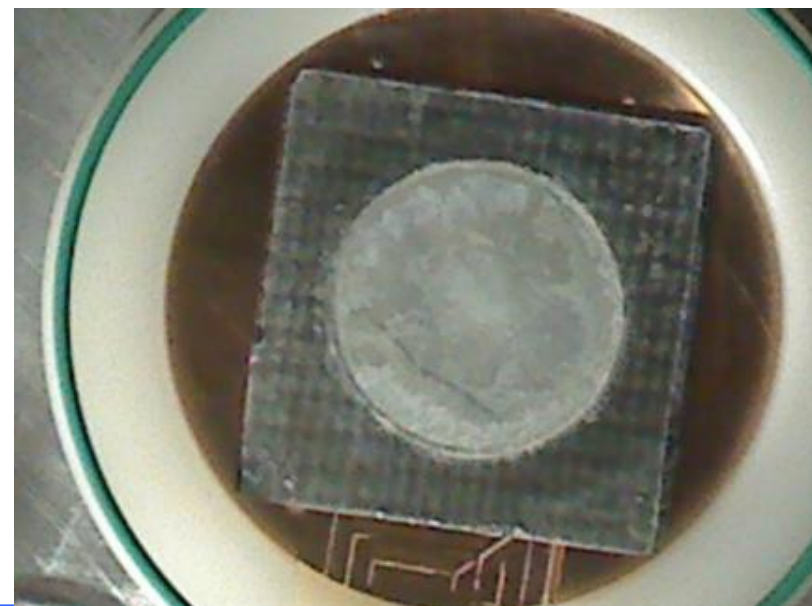
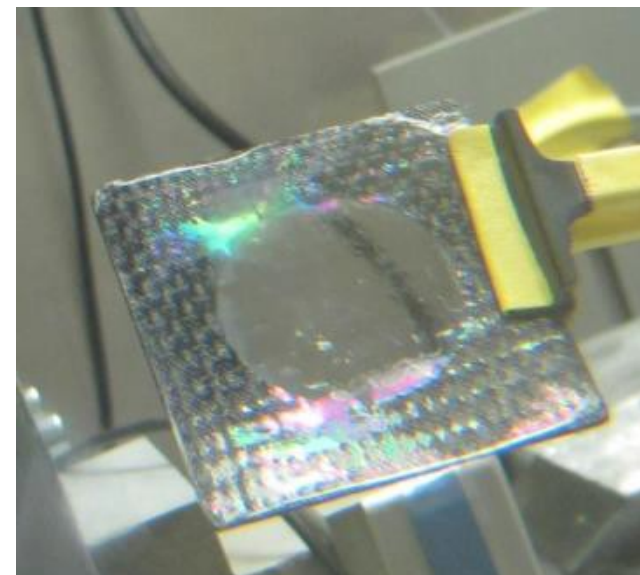
Big Bang Nucleosynthesis & unsolved Cosmological Lithium Problem



2 different samples:
(3.5 μg total mass)

Molecular plating
 Vaporization of droplets

	Vaporization	Molecular Plating
Backing	Stretched PE (0.6 μm)	Aluminum (5 μm)
Activity	20 GBq	19 GBq
Diameter	30 mm	31.6 mm

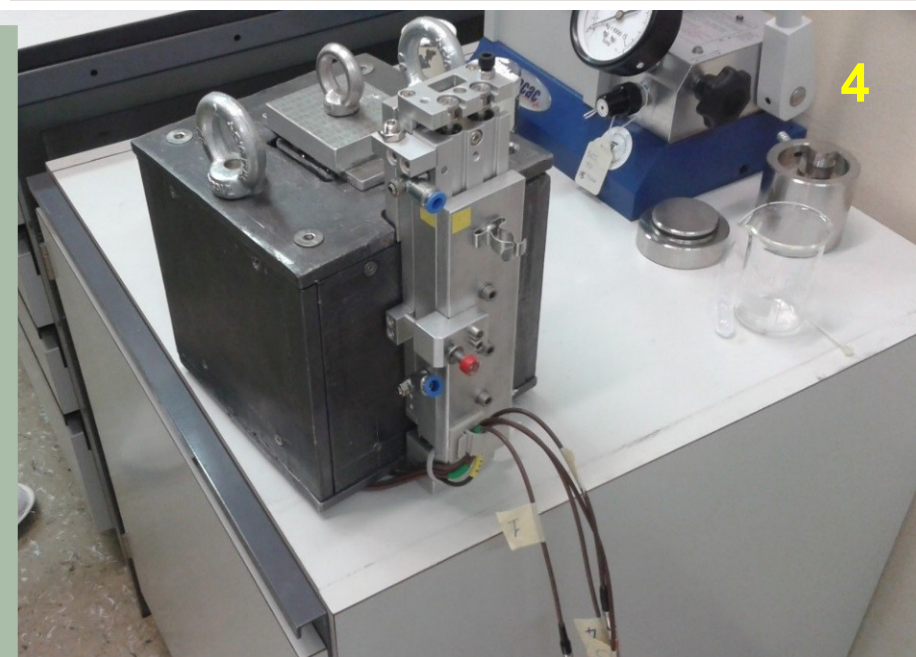
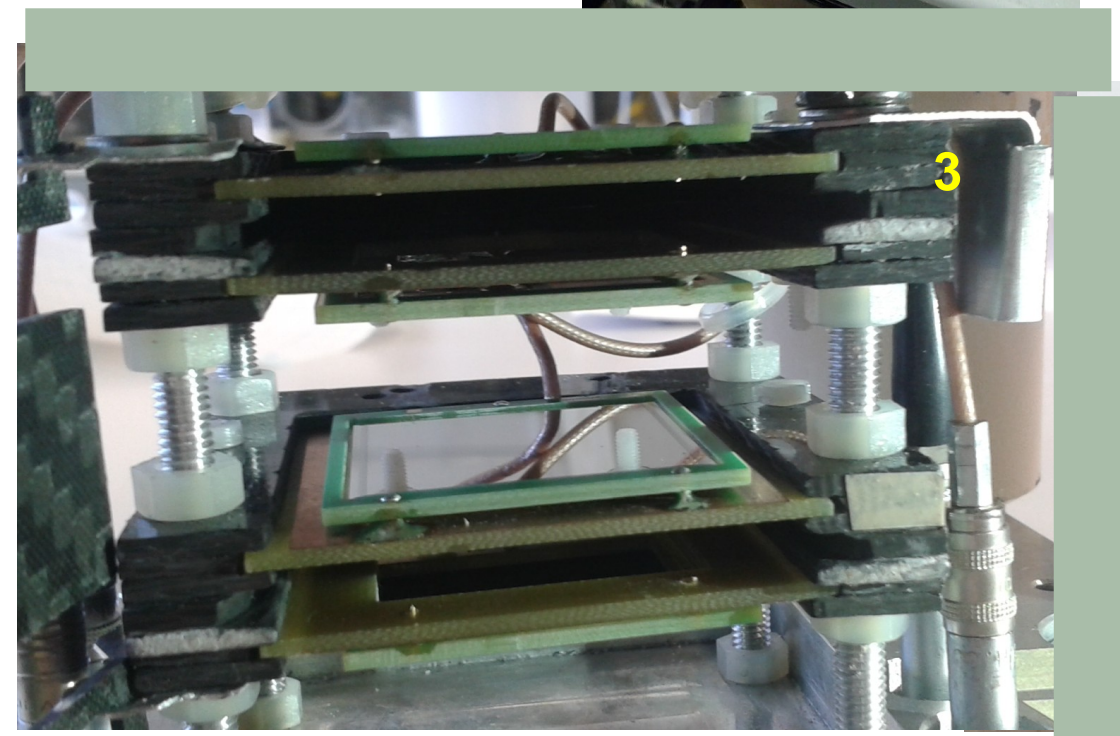
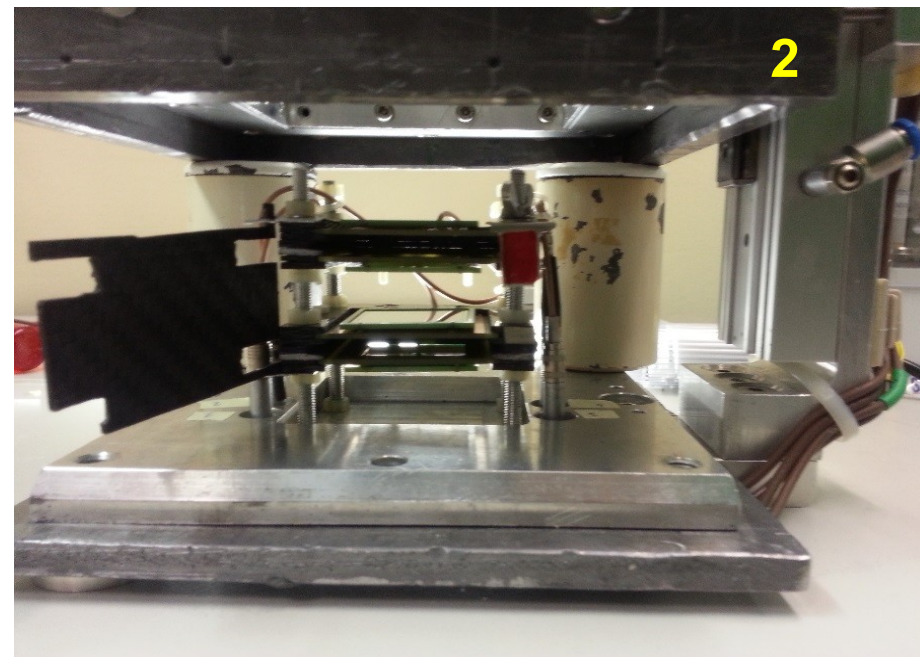
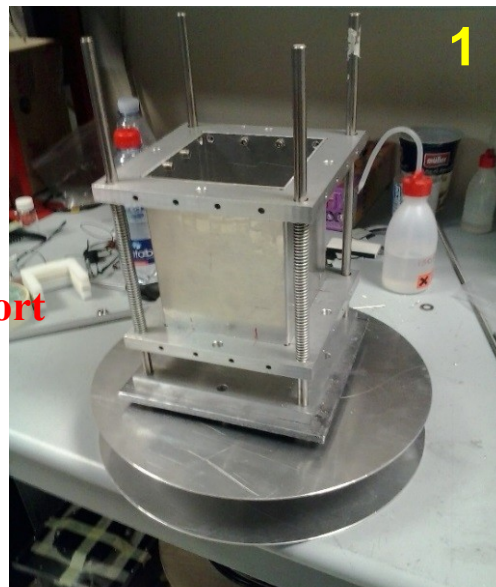


Mechanic and Procedure

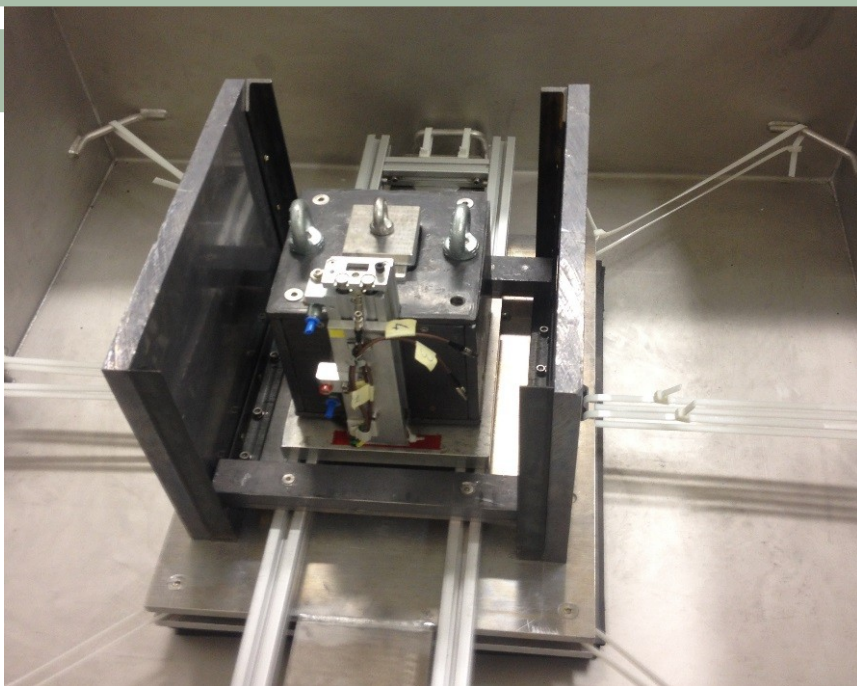
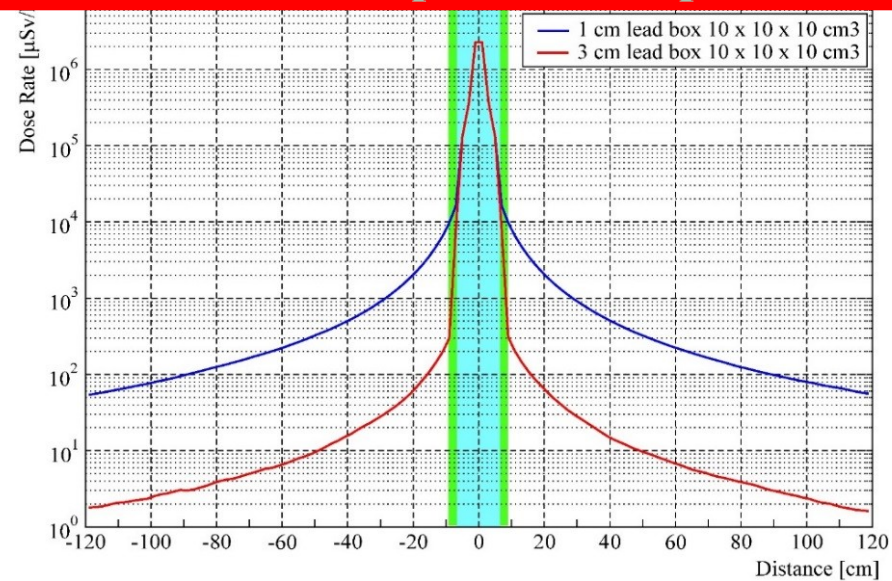
1) bare scattering chamber

2-3) detector and sample support

4) shielded chamber



Insertion of the samples and shipment



$^7\text{Be}(n,\alpha)$ chamber installation in EAR2

Installation at n_TOF-EAR2

