Accelerator version of the

intensive lithium antineutrino source

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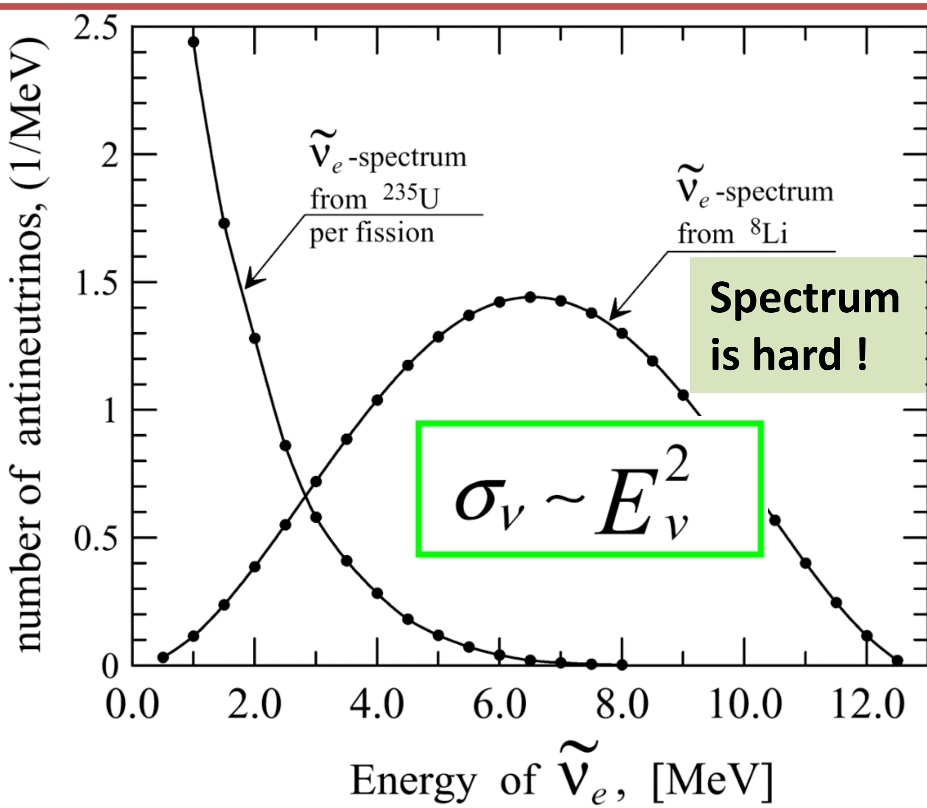
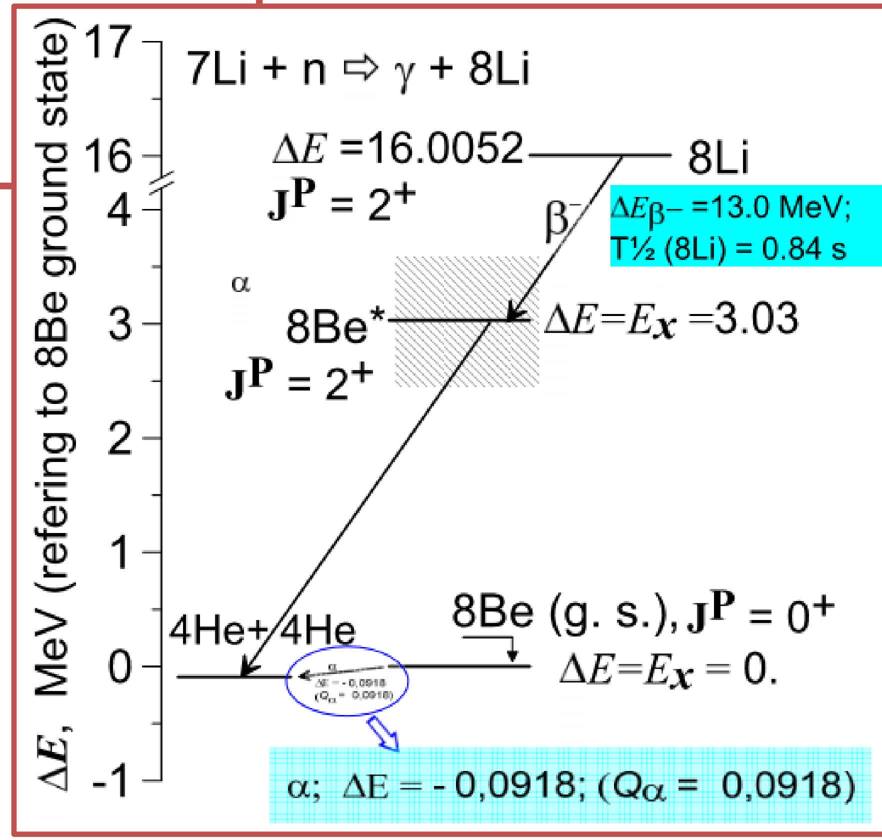
The Conception of the Lithium Antineutrino Source (1)

$^7Li(n,\gamma)^8Li$ $\quad {}^8\text{Li} \xrightarrow{\beta^-} {}^8\text{Be} + e^- + \tilde{\nu}_e$ $\quad T_{1/2}(^8Li) = 0.84$ s

$E_{\tilde{\nu}}^{max} \approx 13.0$ MeV $\quad \bar{E}_{\tilde{\nu}} \approx 6.5$ MeV

(large high cross section for high energy of $\tilde{\nu}_e$!)

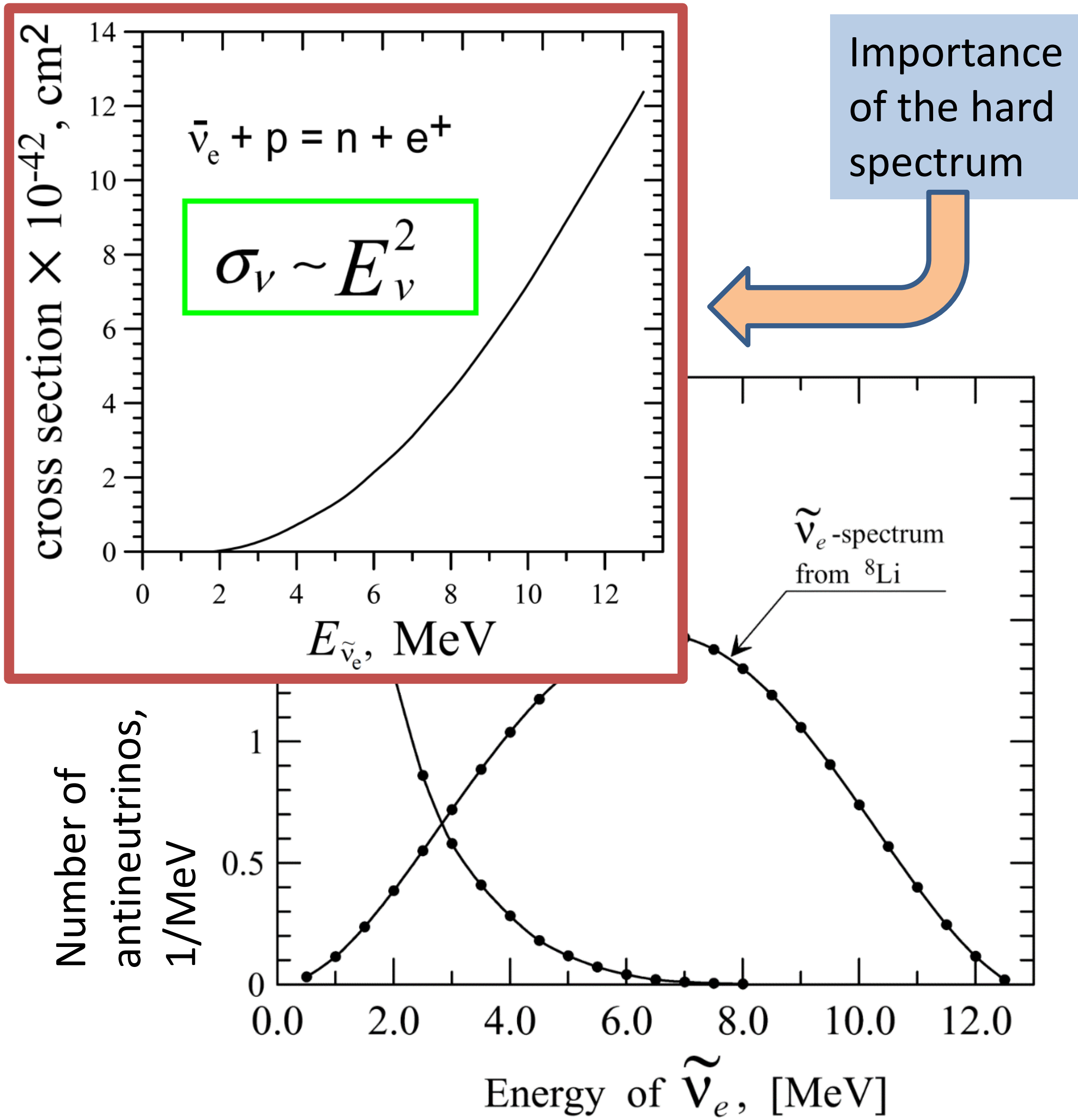




Nucl. Phys. **A745** (2004) 155.

K. Schreckenbach, G. Colvin, W. Gelletly and F. Von Feilitzsch. , Phys. Lett. 160B (1985) 325.
V.G. Aleksankin, S.V. Rodichev, P.M. Rubtsov, F.E. Chukreev, Beta and antineutrino radiation from radioactive nuclei, Energoatomizdat, Moscow, Russia, (1989) ISBN 5-283-03727-4.

The Conception of the Lithium Antineutrino Source (2)



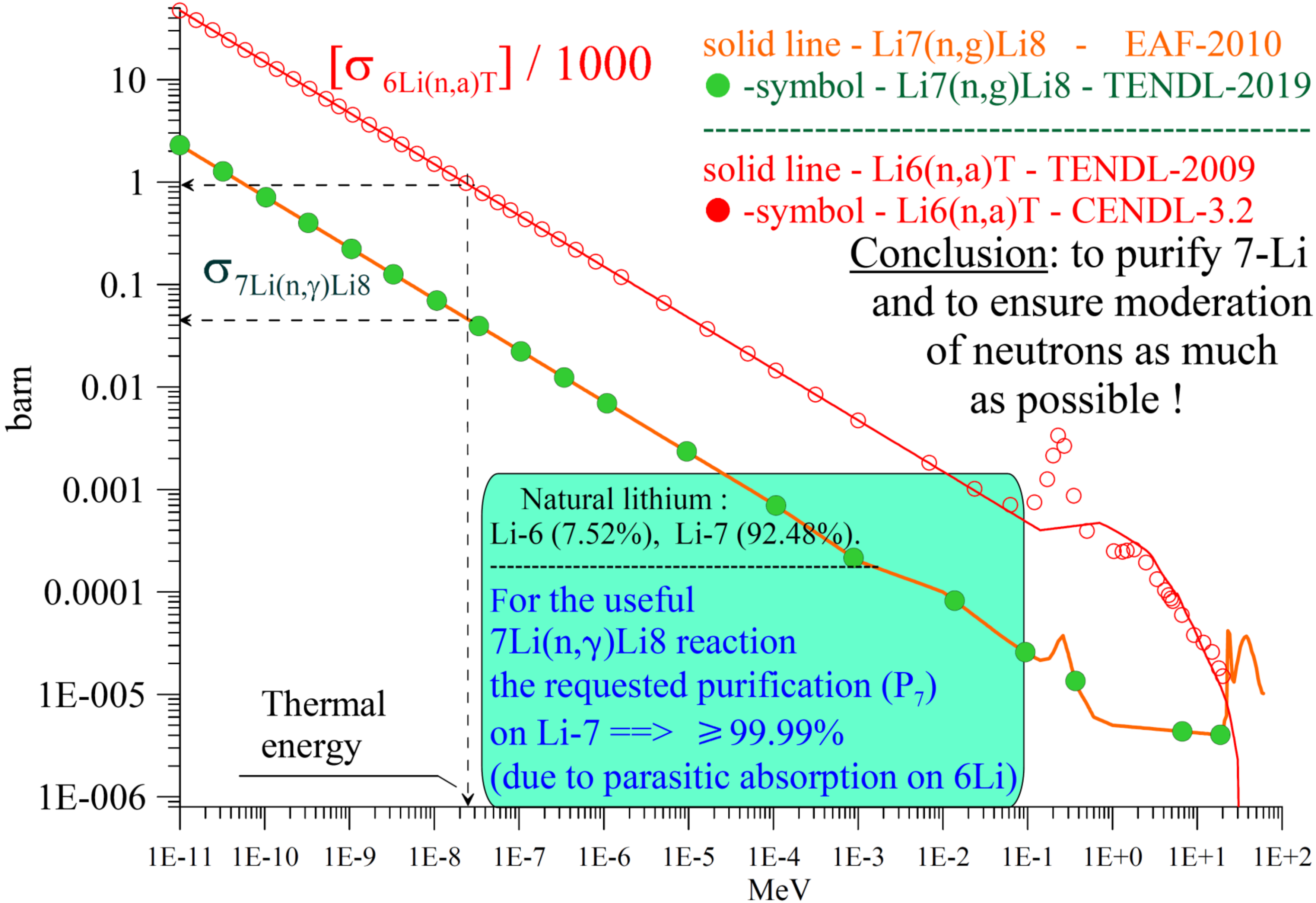
P. Vogel and J.F. Beacom, Phys. Rev. D 60 (1999) 053003

Nuclear reactors (as traditionally used neutrino sources) have a disadvantages – 1) too-small hardness of –spectrum and 2) significant errors.

This disadvantage can be filled having realized the idea to use a high-purified isotope of ^{7}Li for engineering of a neutrons-to-antineutrino Lithium Converter.

The idea to use ^{8}Li isotope as neutrino source was originated by **L.A. Mikaelian, P.E. Spivak and V.G.Tsinoev** (L.A. Mikaelian, P.E. Spivak, And V.G, Tsinoev, Nucl. Phys, v.70, p.574 (1965).

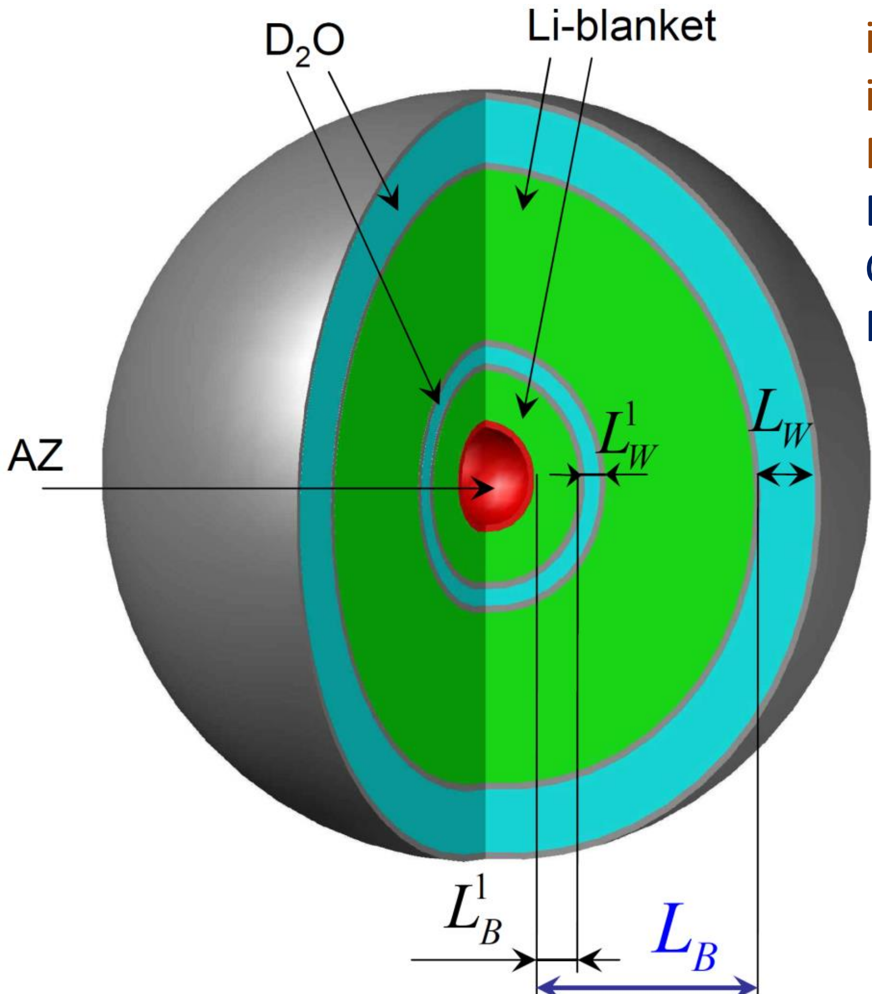
Cross section of Li-7 and Li-8. Requirements for Li-7 purification



V.I. Lyashuk, and Yu.S. Lyutostansky. JETP Letters, 2016, V.103, No.5, pp. 293.

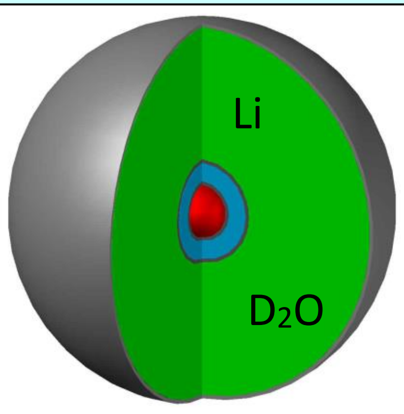
Li-antineutrino Source (reactor version) and proposal history

Lithium blanket in the Li-D_2O scheme is the more compact in comparison with D_2O-Li scheme and and requests the less mass of pure 7Li (in simulation the layer L_B was varied up to 170 cm and L_w – up to 30 cm. R_{AZ} = 23 cm (as for the PIK reactor). The D_2O acts as an effective moderator in D_2O-Li scheme and as a reflector in Li-D_2O scheme. But the more effective (for 8LI production) is the Li-D_2O-Li-D_2O scheme, where the double D_2O layers allow to create the neutron trap.

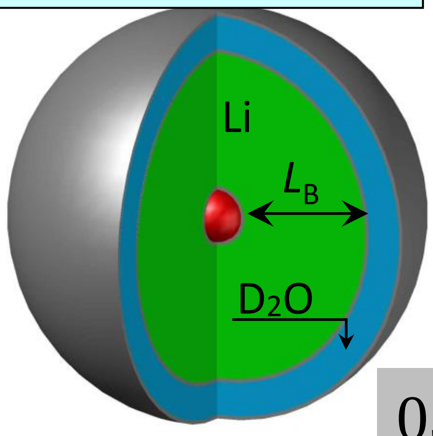


In Kurchatov Institute of Atomic Energy in 70-th it was considered proposal to install Li-blocks into pulse reactor RING (The pulse reactor RING. Preprint IAE, 2384 (1974); in Russian:
Е.Д.Воробьев, Л.А.Микаэлян, А.И.Назаров, С.М.Фейнберг, Я.В.Шевелев, И.Л.Чихладзе, М.С.Юдкевич.ИМПУЛЬСНЫЙ РЕАКТОР "РИНГ“. Препринт ИАЭ, 2384б 1974).

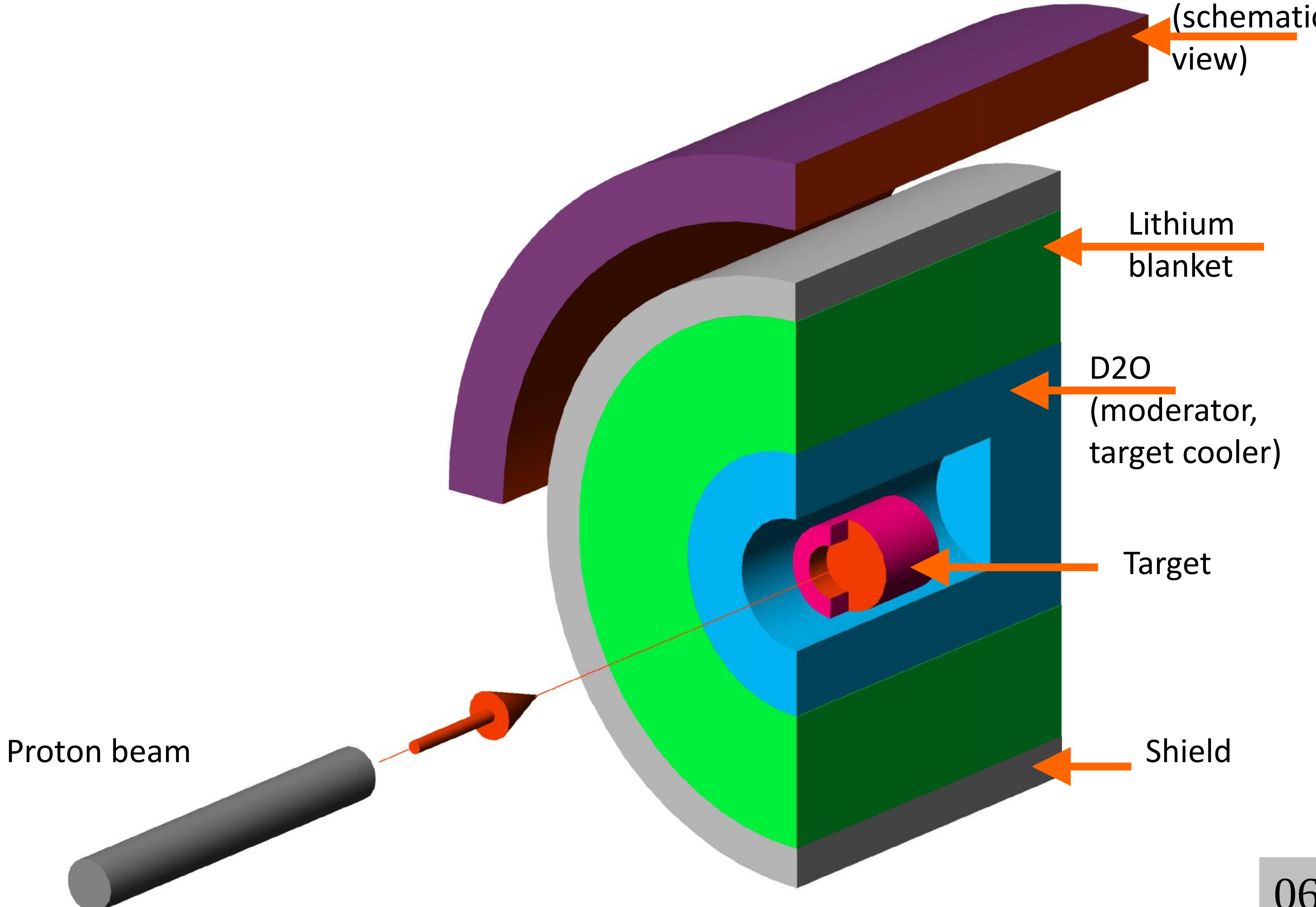
D_2O-Li-scheme



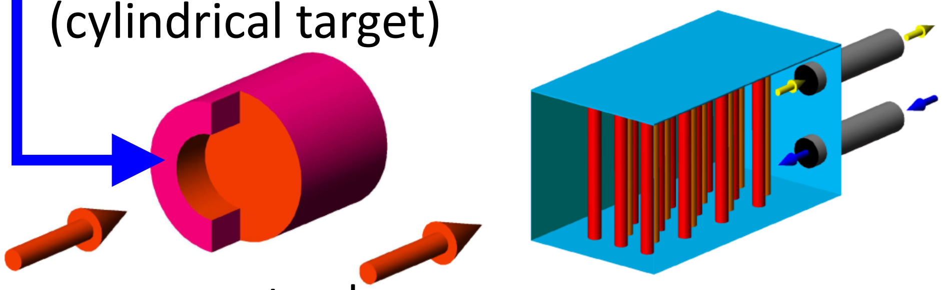
Li-D_2O-scheme



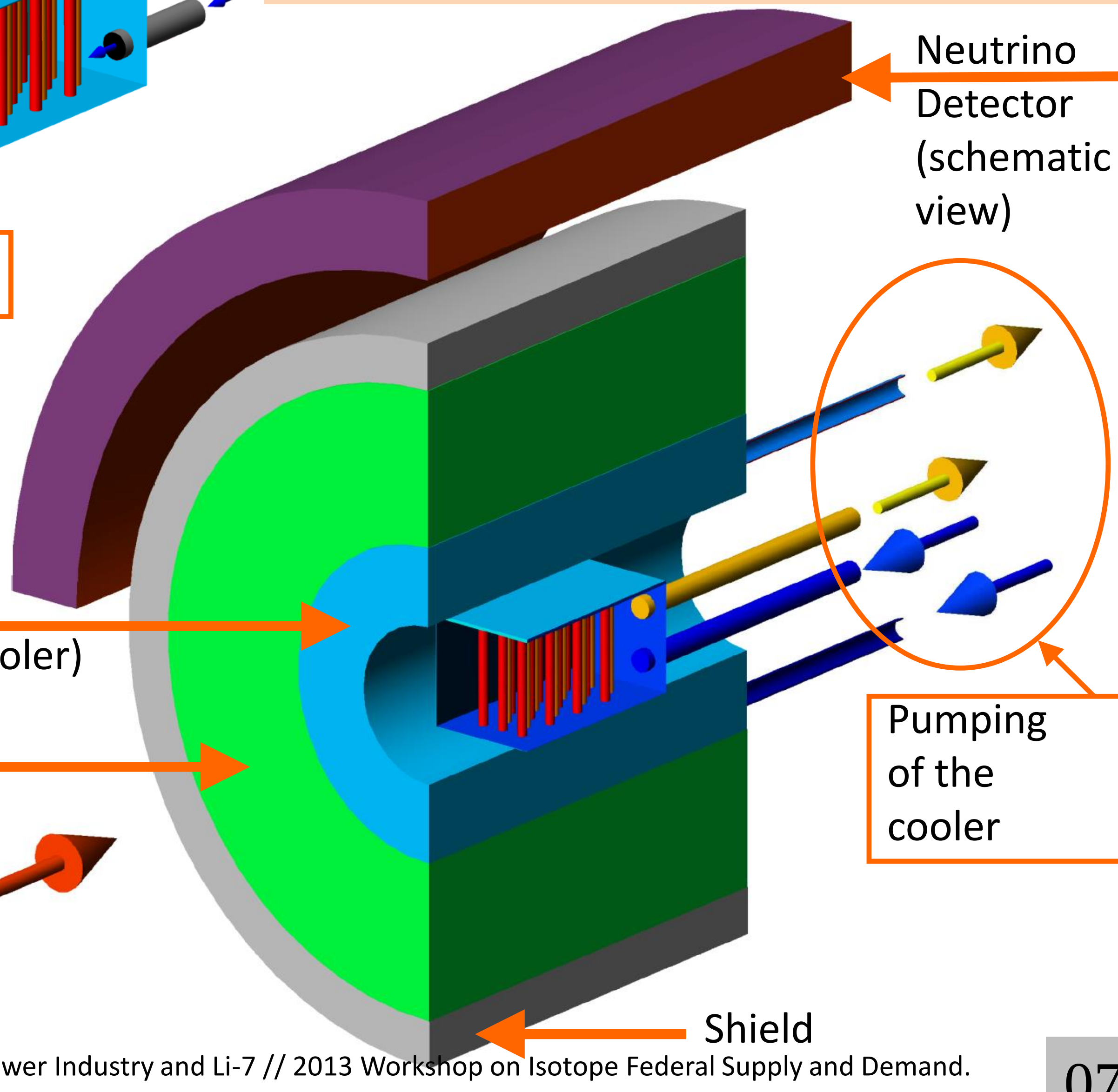
Accelerator scheme of the Li-8 antineutrino source (1).



Lithium $\tilde{\nu}_e$ − source. Accelerator scheme. Variants of the target. (2)



Price of 1 kg of 7Li (with purificarion 99.99%) is k$ (10 – 15).



Reister R. The Nuclear Power Industry and Li-7 // 2013 Workshop on Isotope Federal Supply and Demand.

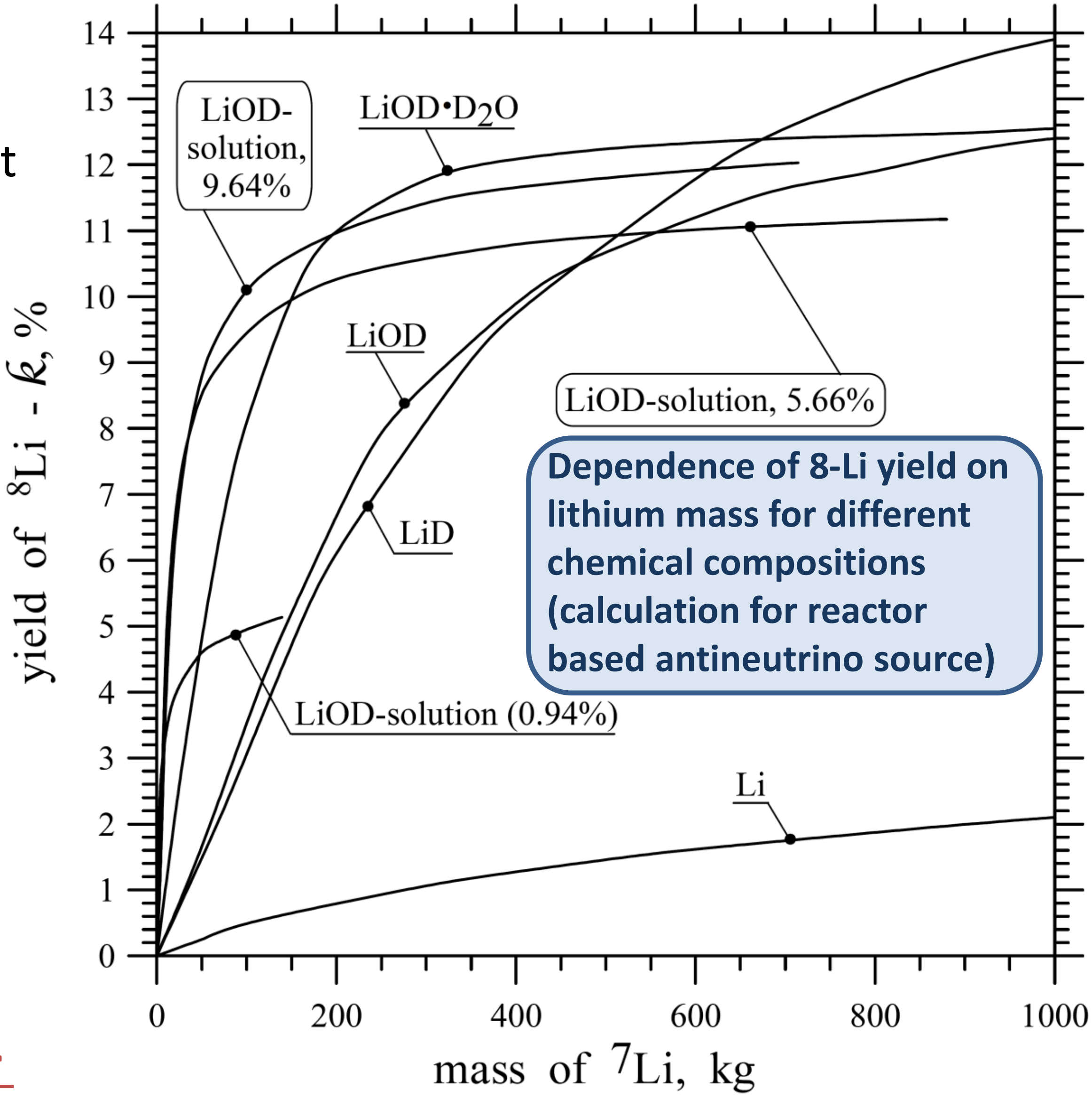
Ault T. et al. Lithium Isotope Enrichment: Feasible Domestic Enrichment Alternatives-2012.

Choise and Optimization of the Li-Blanket Matter

The rise of the of Li-8 yield by increase of the ^{7}Li purity up to 99.999% is difficult for significant lithium mass.

The solution is to use not metal ^{7}Li isotope (as the blanket material) but it chemical compositions with high moderator capability. For example the perspective matter are the $LiOD \cdot D_2O$, *LiD* and heavy water solution of lithium hydroxide *LiOD.*

So, <u>at the LiOD solution with concentration 9.46 % for the achievement κ = 7.7% the necessary Li-mass will be in 300 times less than for the blanket with metal lithium (in case of reactor scheme).</u>



Dependence of 8-Li yield on lithium mass for different chemical compositions (calculation for reactor based antineutrino source)

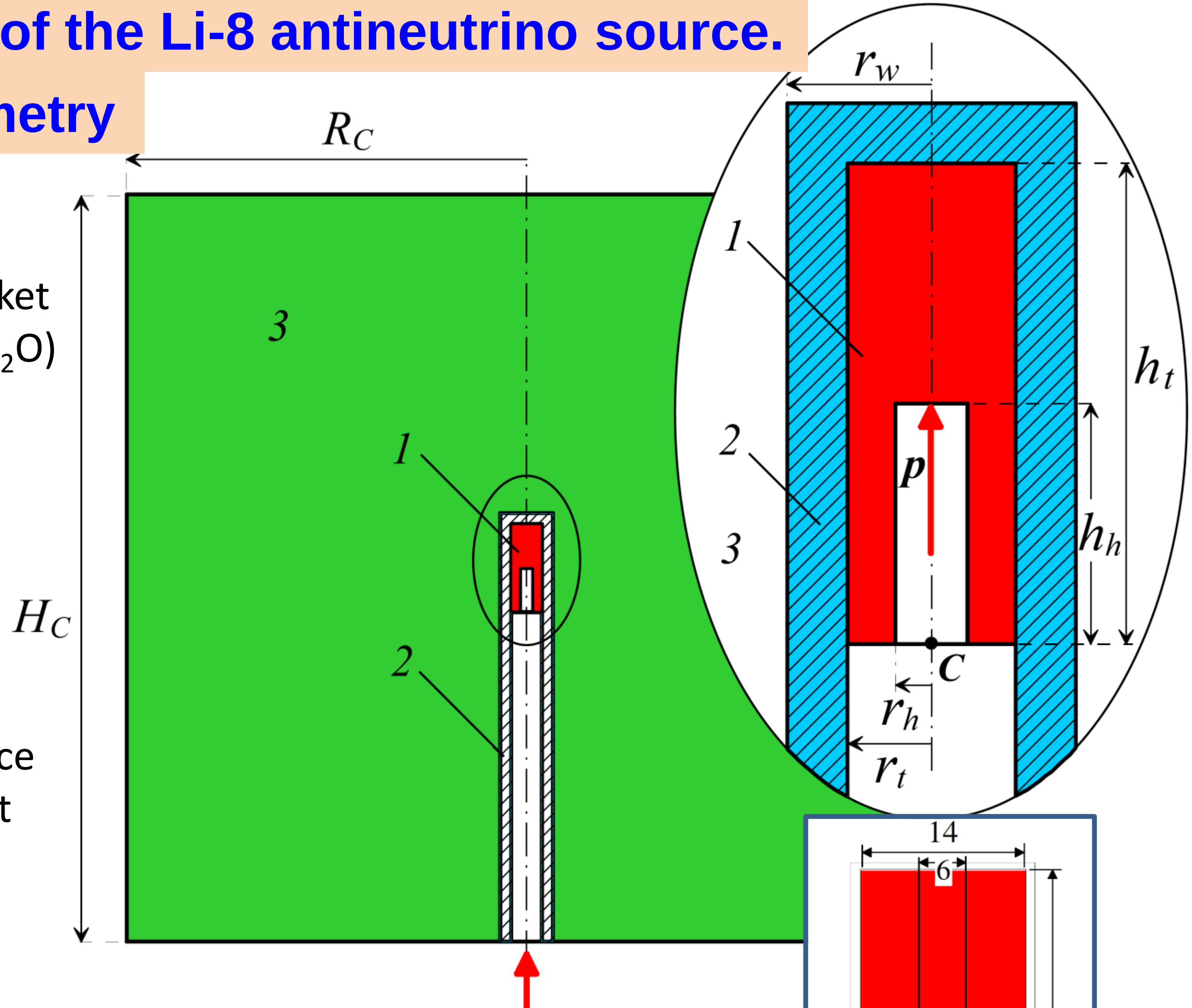
Lyashuk V. I. Particles and Nuclei, Letters. 2017. V.14. No.3. p. 465.

Accelerator scheme of the Li-8 antineutrino source.

The cylindrical geometry

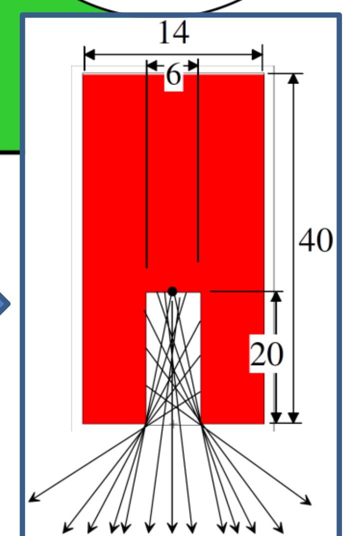
1 - W-target
2 - D_2O-channel
3 - LiOD-volume (lithium blanket with LiOD 9.46% solution in D_2O)
H_c=338 cm
R_c = 182 cm
h_t = 30-40 cm
Ep = 200 MeV

k_p ~ 0.27 (Yield of Li-8 per proton)
(2.1E+23 – antineutrino fluence during 5 years at 1 mA current and for the 80% of used time of the accelerator)

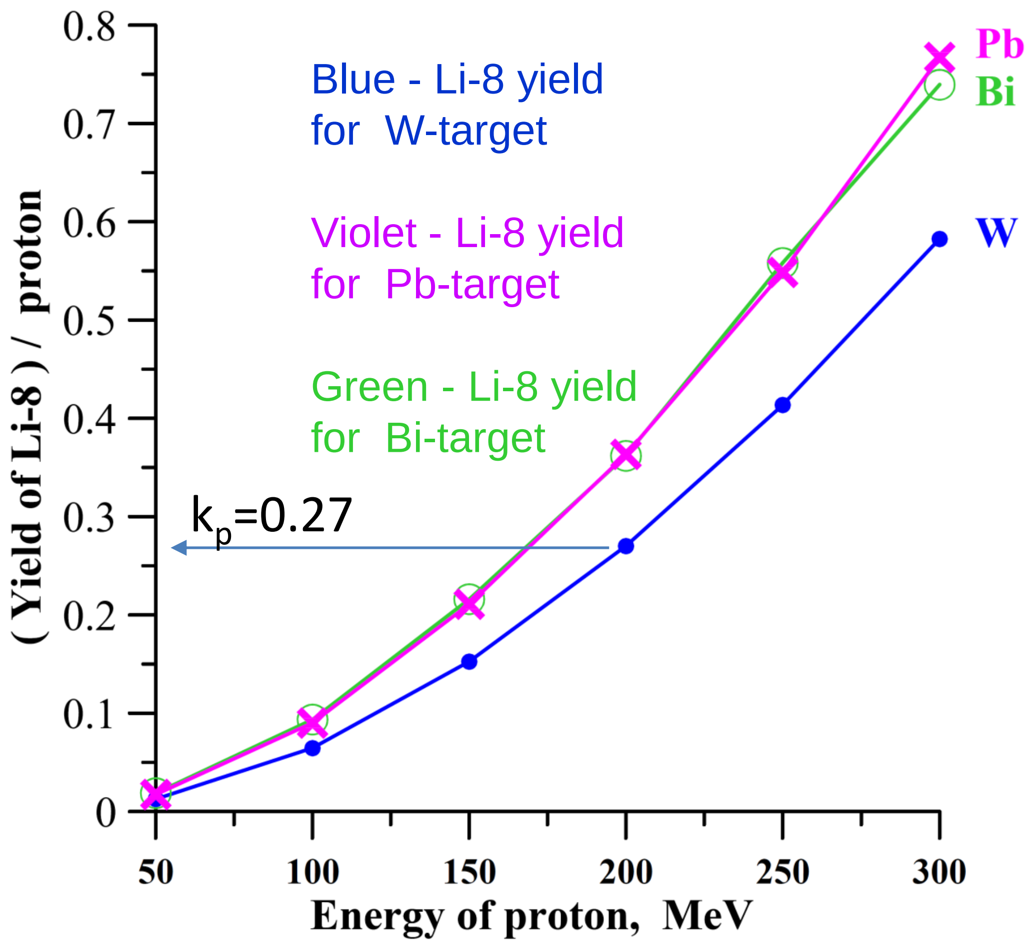


V.I. Lyashuk and Yu.S. Lutostansky. Bull. Russ.Acad. Sci. Phys, 2015, vol.7, p.431–436.

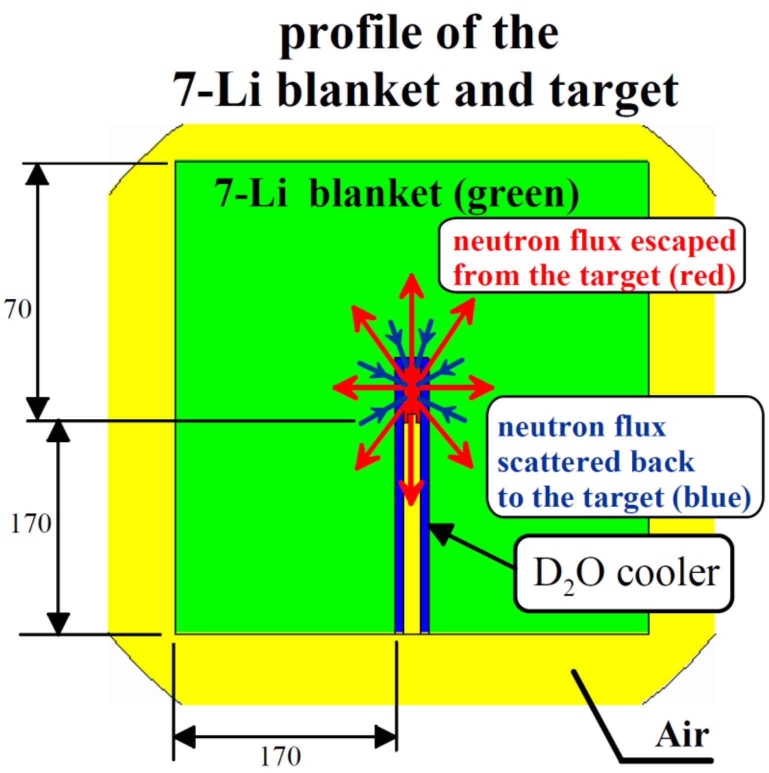
The target was optimized: the Loss of back escaped neutrons was decreased down to 2% rel. to total escaped neutrons



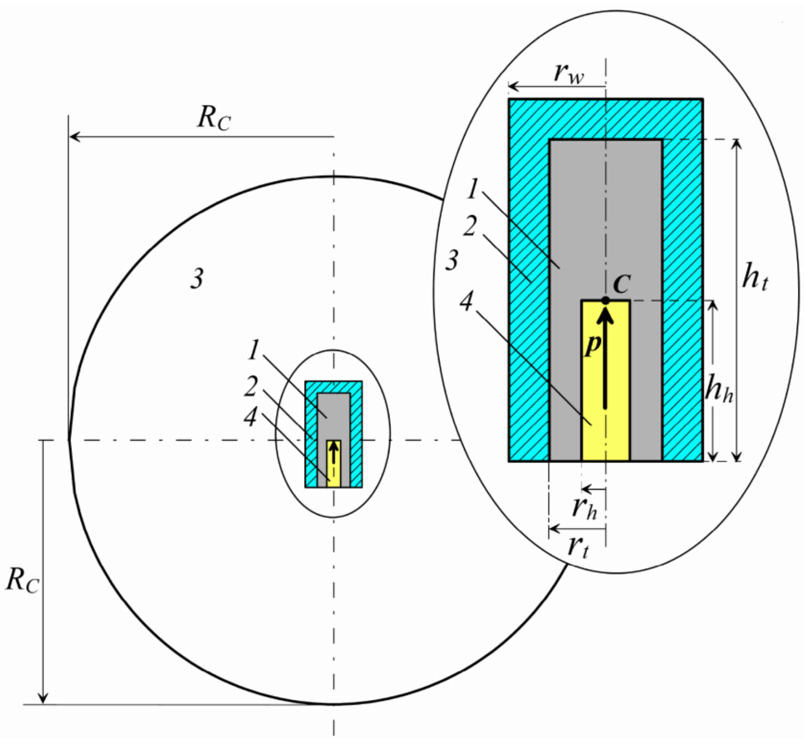
Accelerator scheme of the Li-8 antineutrino source. Yield of Li-8 in case of W, Pb and Bi-targets.



7-Li blanket
(0.9999-purity of 7Li):
9.46% LiOD solution
in D_2O heavy water



REQUIREMENTS to DEUTERIUM PURIFICATION for USE of DEUTERIZED LITHIUM COMPAUNDS and D_2O-heavy water

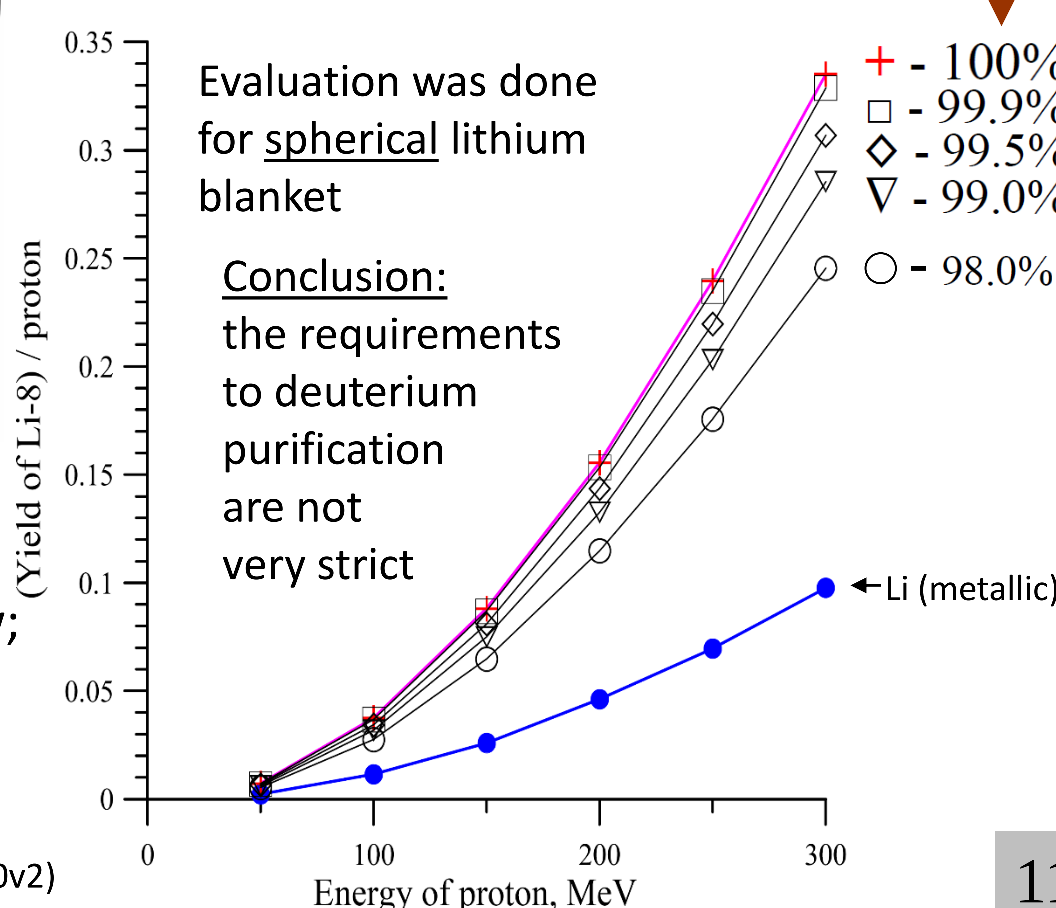


Yield of 8Li in the blanket with variants: 1) 9.46% LiOD solution in D_2O with different purification of D; 2) metallic 7Li.Proton energy - E_p= (50-300) MeV

Grade of D-purity

Evaluation was done for spherical lithium blanket

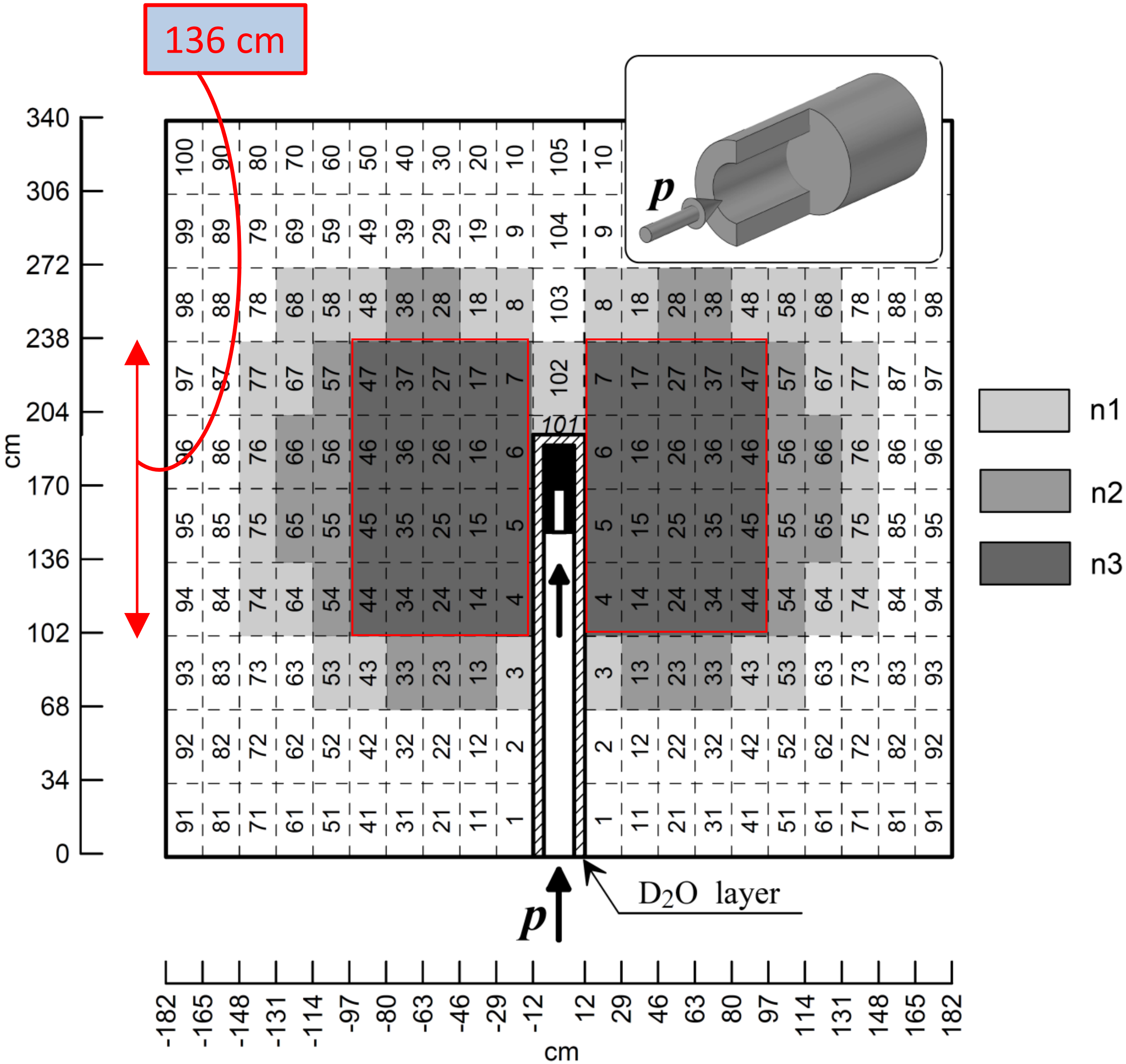
Conclusion: the requirements to deuterium purification are not very strict



Spherically-cylindrical geometry:
1- W- target; *2* – D2O layer;
3 – lithium blanket; 4 target window;
R_c=112 cm; h_t=40 cm; r_t= 7 cm;
r_w=15 cm; h_h=20 cm; r_h=3 cm.

(Lyashuk V. I. and Lutostansky Yu. S. arXiv:1503.01280v2)

Accelerator scheme of the Li-8 antineutrino source. Geometry of the lithium blanket, proton beam channel and tungsten target.



The boundaries of 105-cylindrical-cells in the blanket volume (filled with LiOD in D_2O solution) are indicated as dashed lines.

The volume regions corresponding to 90%, 80% and 68% yields (of the total 8Li yield in the blanket volume) are shown by halftones (as n1, n2, n3).

The data are obtained for proton energy 200 MeV.

The mass of 7Li (of 99.99% - purification) corresponding to volumes of the cells n1, n2 and n3 are 420, 241 and 128 kg correspondingly compare to ~1.1 t for the total volume of the all cells.

Lyashuk V. I. // Results in Physics, v6, 2016, p 961; Lyashuk V. I. arXiv:1609.02127. 2016

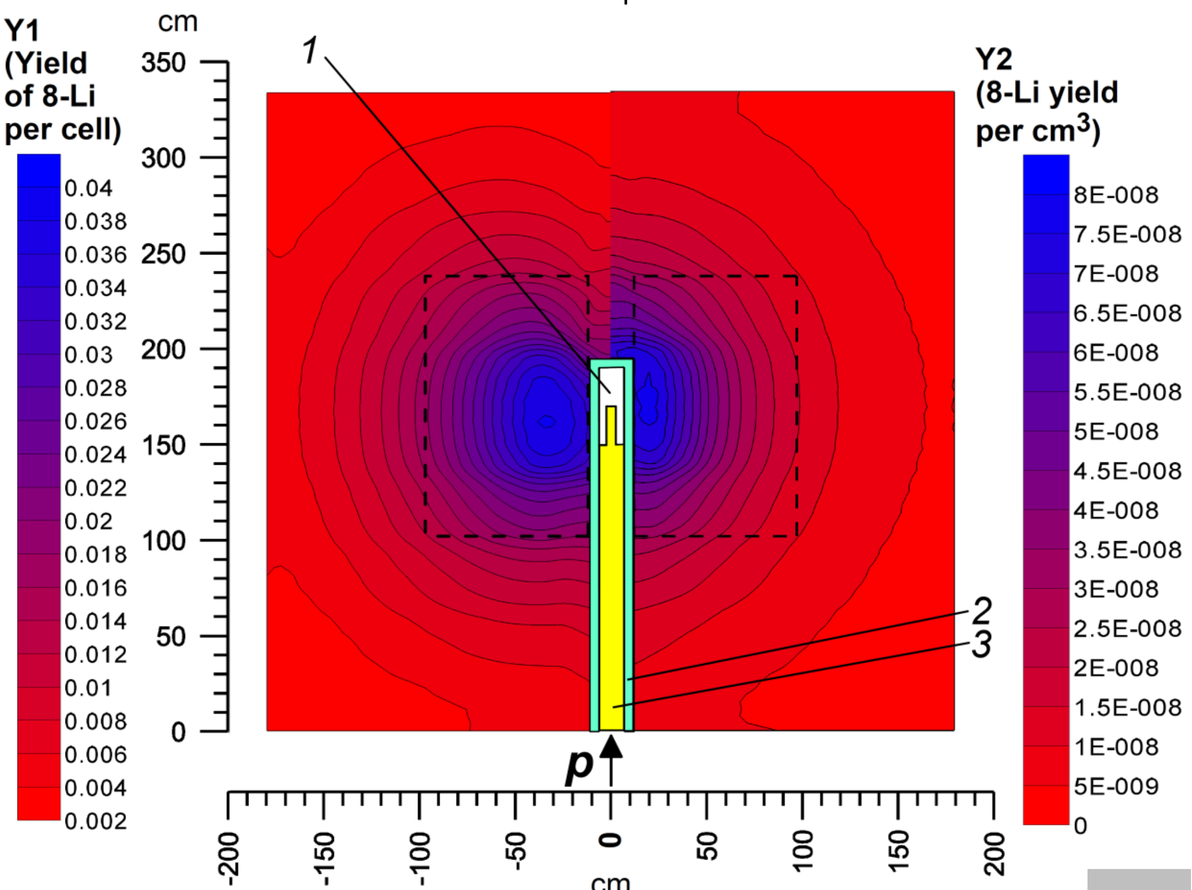
Accelerator scheme of the Li-8 antineutrino source.
Contour plot for Density of Li-8 yield and Li-8 yield in the cells.

The figure combined two graph (8Li yield in the cells and density of 8Li creation) in the contour map. The left part - is the level lines for the smoothed 8Li yield in the cells, on the right - density of 8Li yield per cm^3.

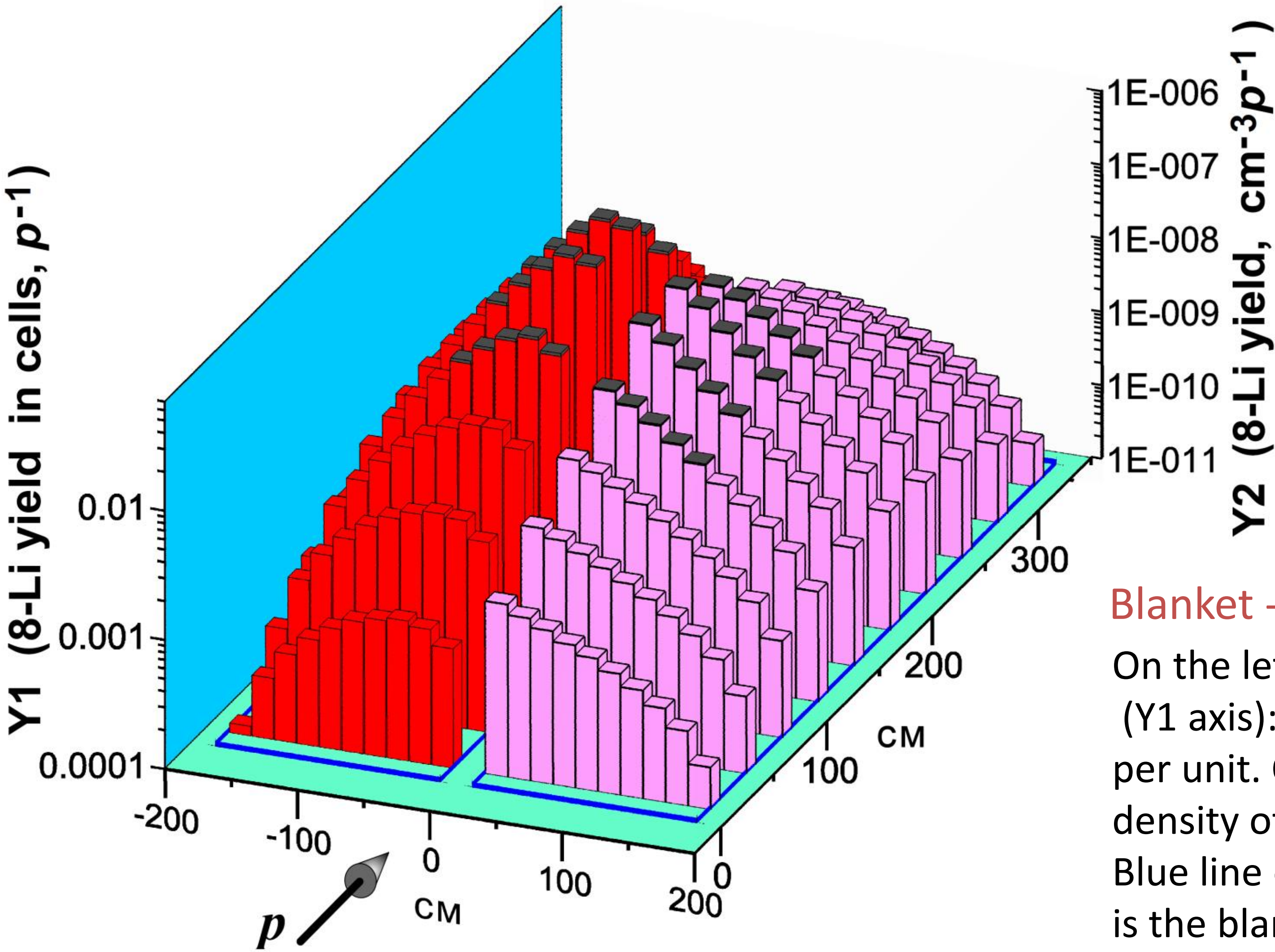
The dotted line shows the region corresponding 68% of 8Li yield.

The yields and densities of 8Li creation are normalized per proton (E_p = 200 MeV).

Yield of 8Li in the cylindrical blanket (horizontal axis - the size in radius; vertical dimension – the cylinder axis).
Left to the proton beam - 8Li normalized yield in cells - see Y1 axis.
On the right - density of 8Li creation -see Y2 axis.
1 - target.
2 - D2O-channel for target cooling.
3 - channel of the proton beam.



Accelerator scheme of the Li-8 antineutrino source.
Histograms for Density of Li-8 yield and Li-8 yield in the cells.



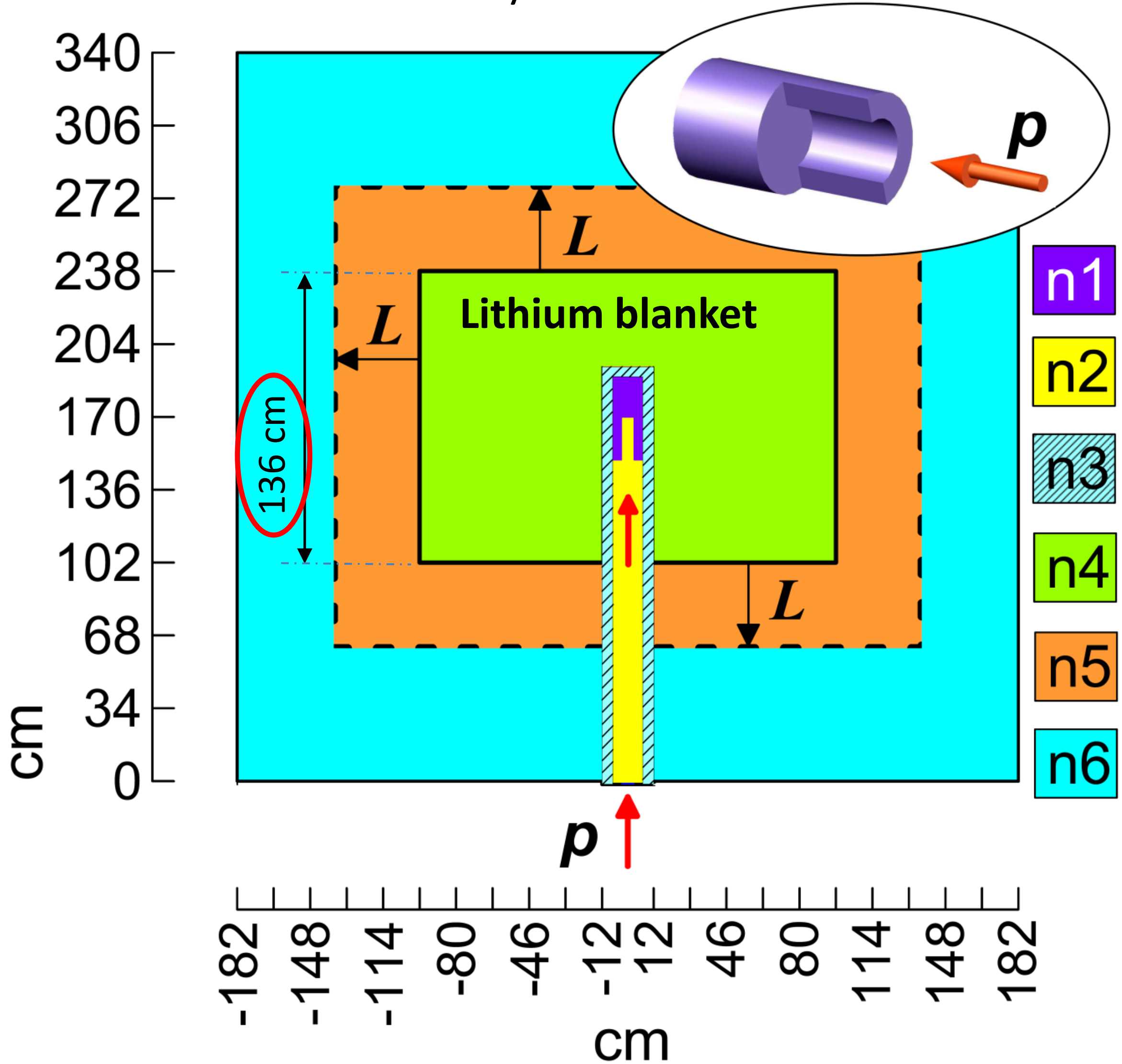
Blanket - 9.46% LiOD solution

On the left to the proton beam (Y1 axis): 8Li yield normalized per unit. On the right (Y2 axis): density of 8Li yield.
Blue line on the horizontal plane is the blanket cross section.
Histograms with black top correspond to 68% of total 8Li yield in the blanket.

Lyashuk V.I. Result in Physics, 2016. 6. 961.
Lyashuk V.I. arXiv:1609.02127 [physics.ins-det]. 2016.

Accelerator scheme of the Li-8 antineutrino source. Geometry for decrease of the lithium blanket dimension.

To obtain the discussed ^{8}Li yield we need to ensure the outside neutron reflector and moderator



Cross section of the lithium blanket:

n1 – target,

n2 – empty channel,

n3 - D2O cooler,

n4 – lithium blanket,

n5 – carbon layer of variable thickness *L*,

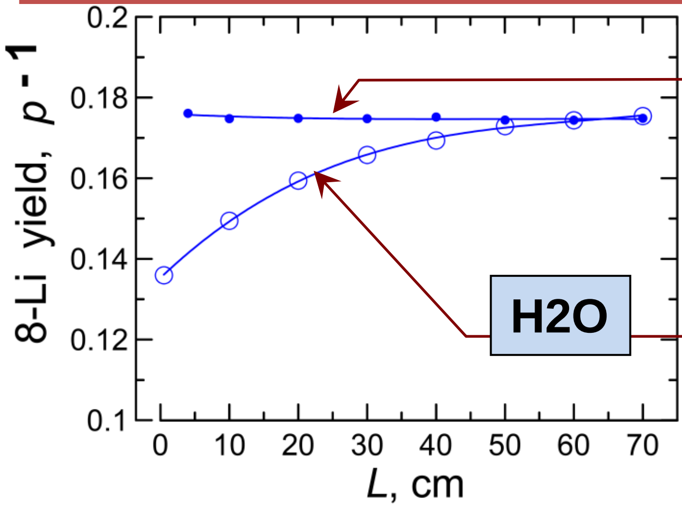
n6 – water (D2O or H2O).

For obtained decreased dimension the k_p ~ 0.175 (Yield of Li-8 per proton at Ep=200 MeV; i.e., 65% (that is **<u>very close</u>** to the expected 68% of the initial efficiency k_p= 0.27)

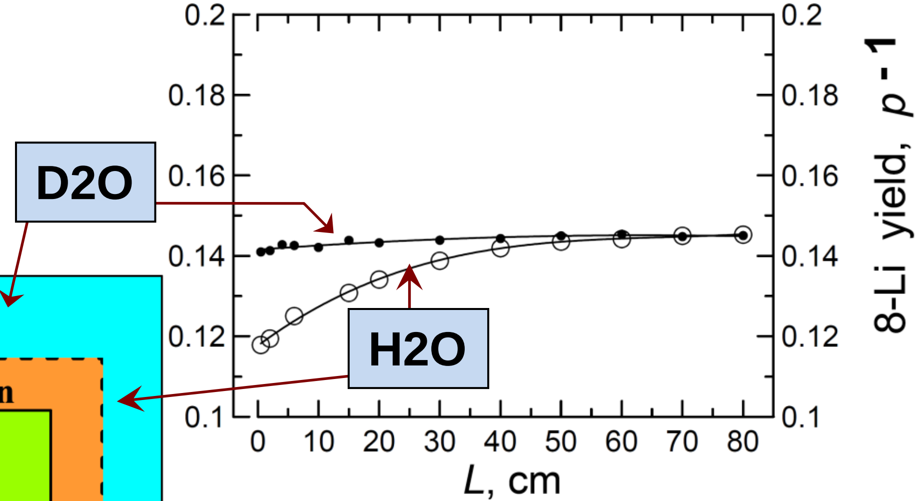
Lyashuk V. I. // Results in Physics. V.6, 2016, p. 961.

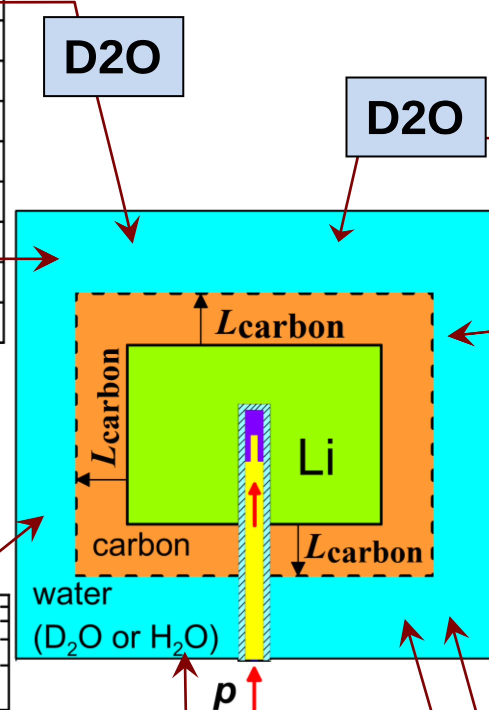
YIELD of 8Li and ESCAPE of NEUTRONS DEPENDING on the CARBON THIKNESS *L* (at purity of D – 99.9% and 99.0%; and at replace of outer layer of heavy water D_2O with light H_2O water)

Yield of 8Li at purity of D – 99.9%

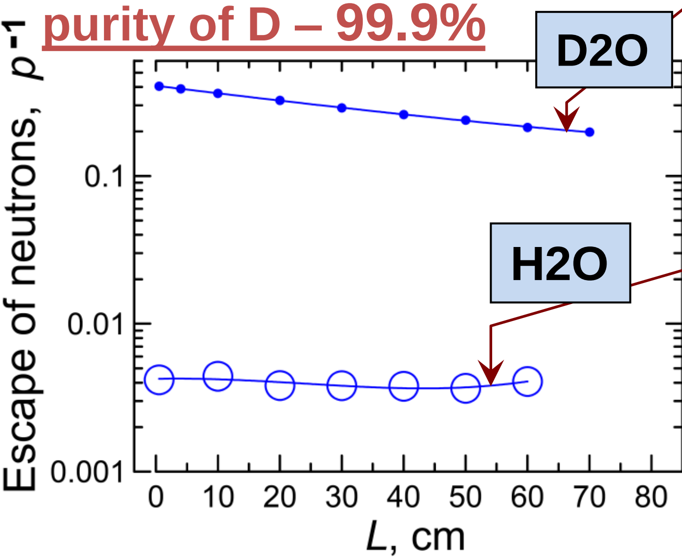


Yield of 8Li at purity of D – 99.0%

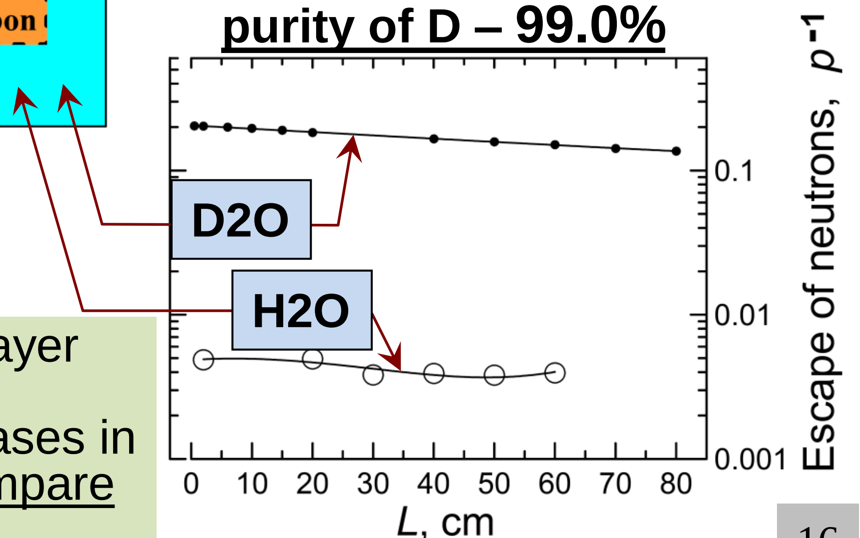




Escape of neutrons at purity of D – 99.9%



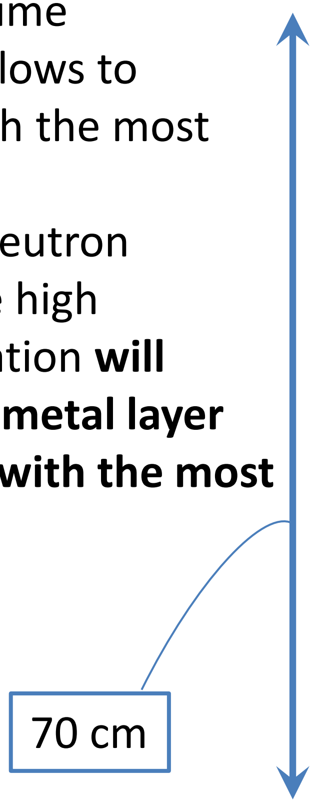
Escape of neutrons at purity of D – 99.0%

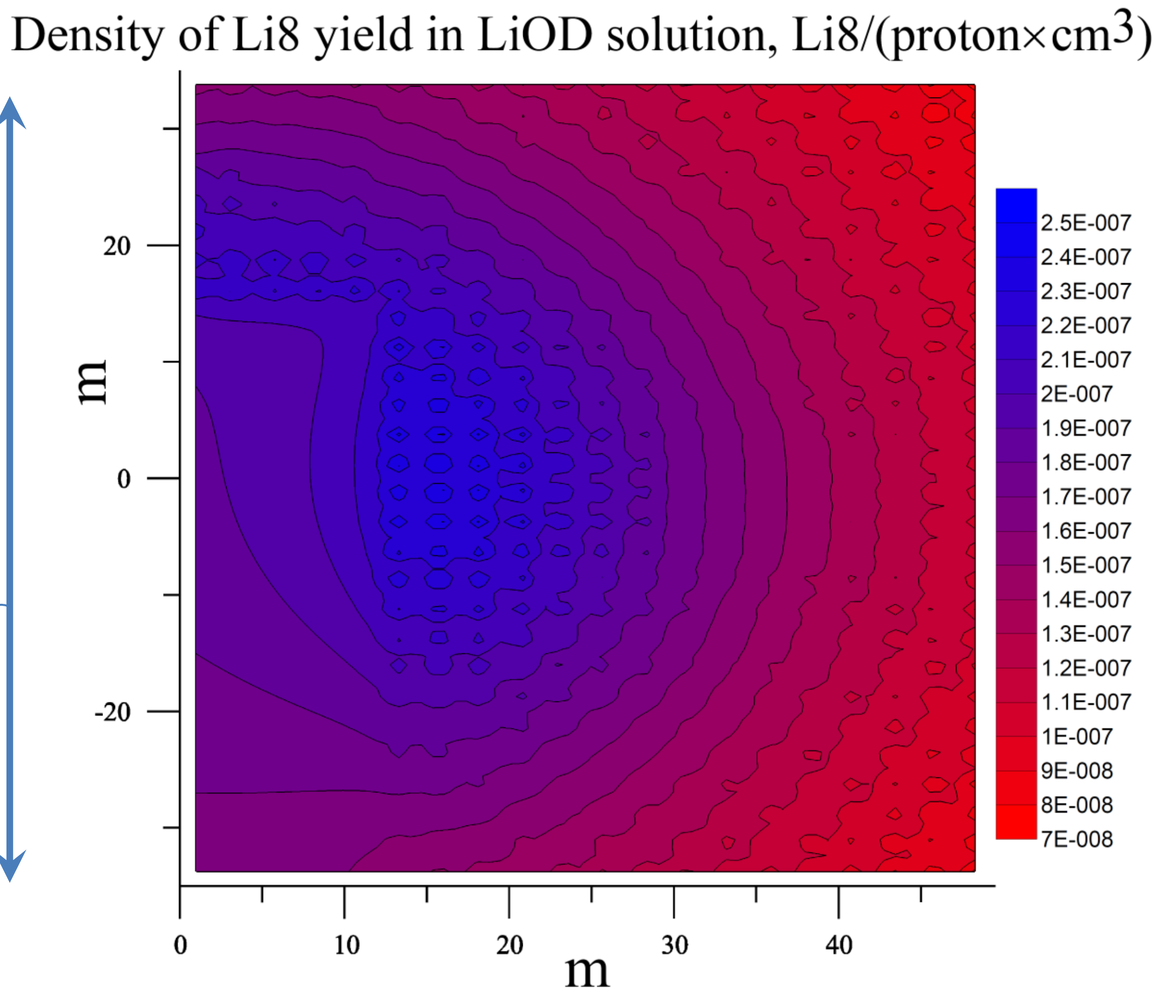


For outer H_2O layer the escape of neutrons decreases in 40-60 times compare to D_2O case

Accelerator scheme of the Li-8 antineutrino source. The proposed solution to create an effective Li-8 antineutrino source with diminished dimensions.

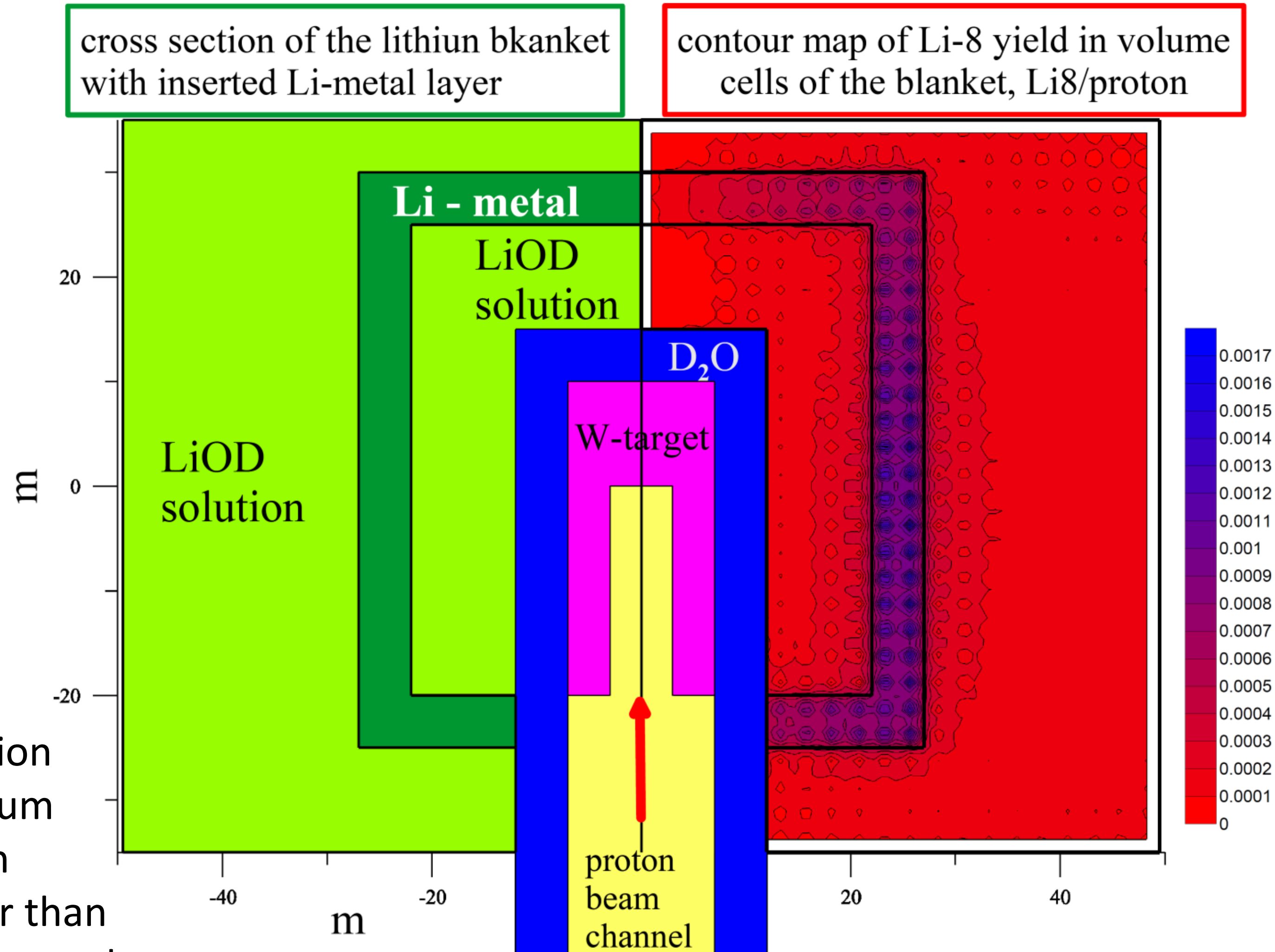
- Analysis of the Li-8 production in the volume Li-8 /(proton x cm^3) allows to indicate the space with the most high creation of Li-8;
- In case of effective neutron moderation the more high rate of 7Li(n,γ)Li8 creation **will be ensured by thin Li-metal layer inserted in the space with the most high creation of Li-8**.



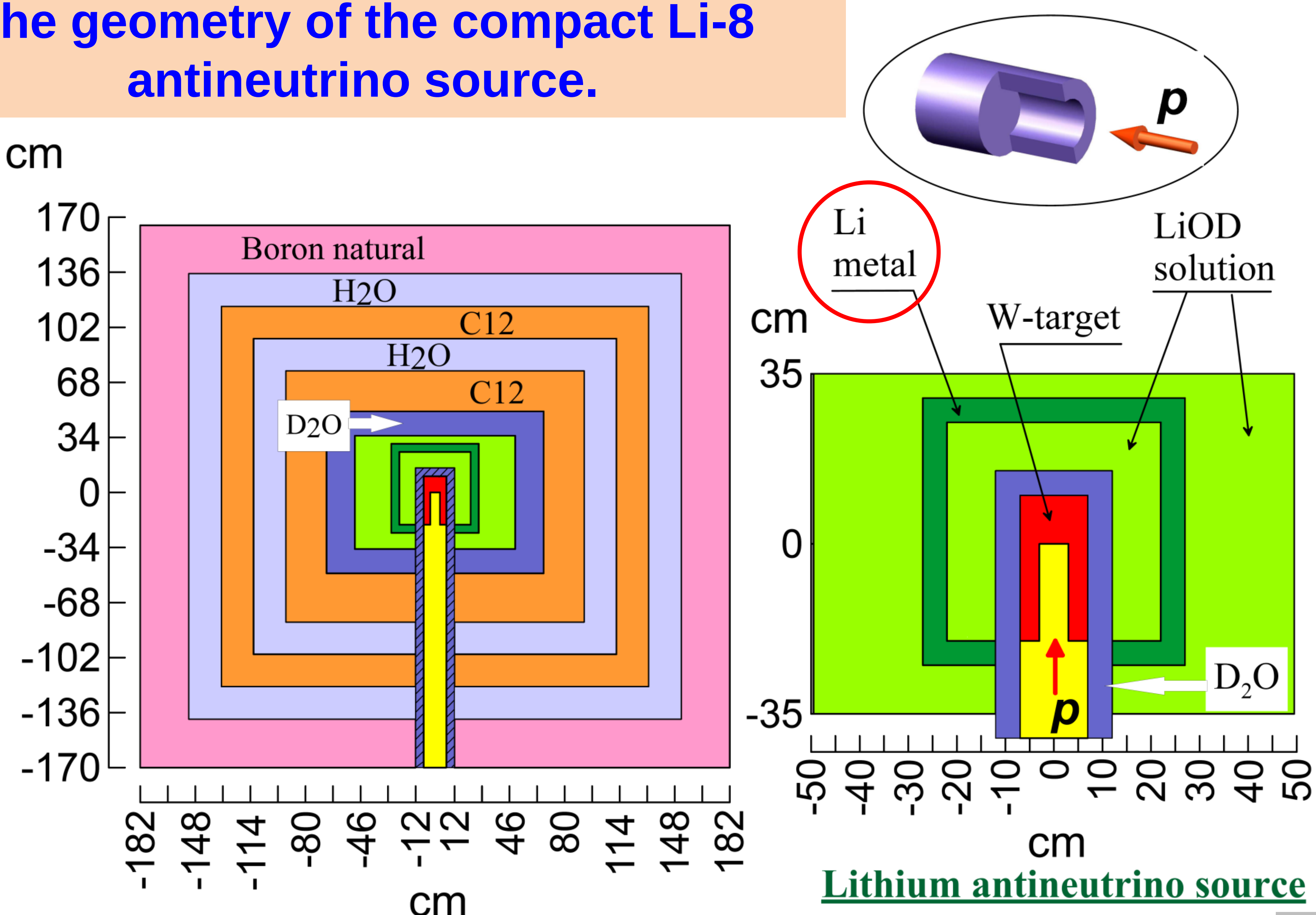


Accelerator scheme of the Li-8 antineutrino source. The proposed solution to diminish the dimension of the Li-8 antineutrino source (continue).

<u>Proposed solution:</u>
the inserted thin **<u>metal</u>** Li-7 layer (purification 99.99%) allows to obtain an increase of Li-8 yield more close to the target channel (see right part of the Figure).
Reason for proposal: the nuclear concentration of 7Li nuclei in the lithium metal (with purification 99.99% on 7Li) is higher than it concentration in the outer heavy water solution of 7LiOD in ~18 times.



Accelerator scheme of the Li-8 antineutrino source.
The geometry of the compact Li-8 antineutrino source.



Lithium antineutrino source

Accelerator scheme of the Li-8 antineutrino source.

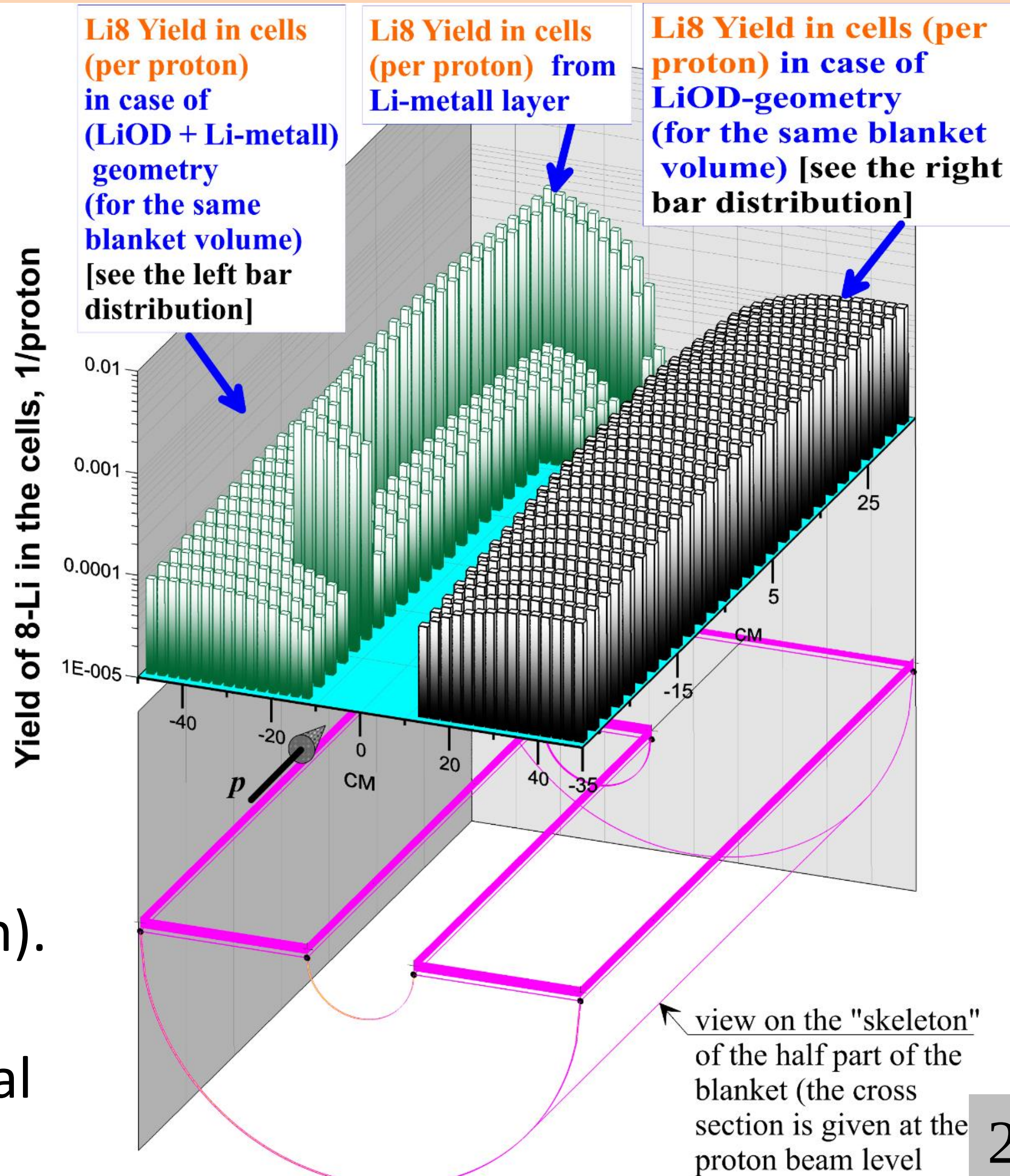
Comparison of Li-8 yield in volume cells of the lithium blankets for cases of (LiOD solution + Li-metal layer) and case of LiOD solution.

Lengh of this diminished lithium blanket is 70 cm (along the beam axis) compare to the previous geometry with 136 cm in lenth.

The mass of the Li-7 in the diminished lithium blanket is 67.5 kg compare to 128.3 kg of previous geometry.

The obtained Li-8 yield is k_p = 0.13 compare to 0.175 in the previous case (L=136 cm).

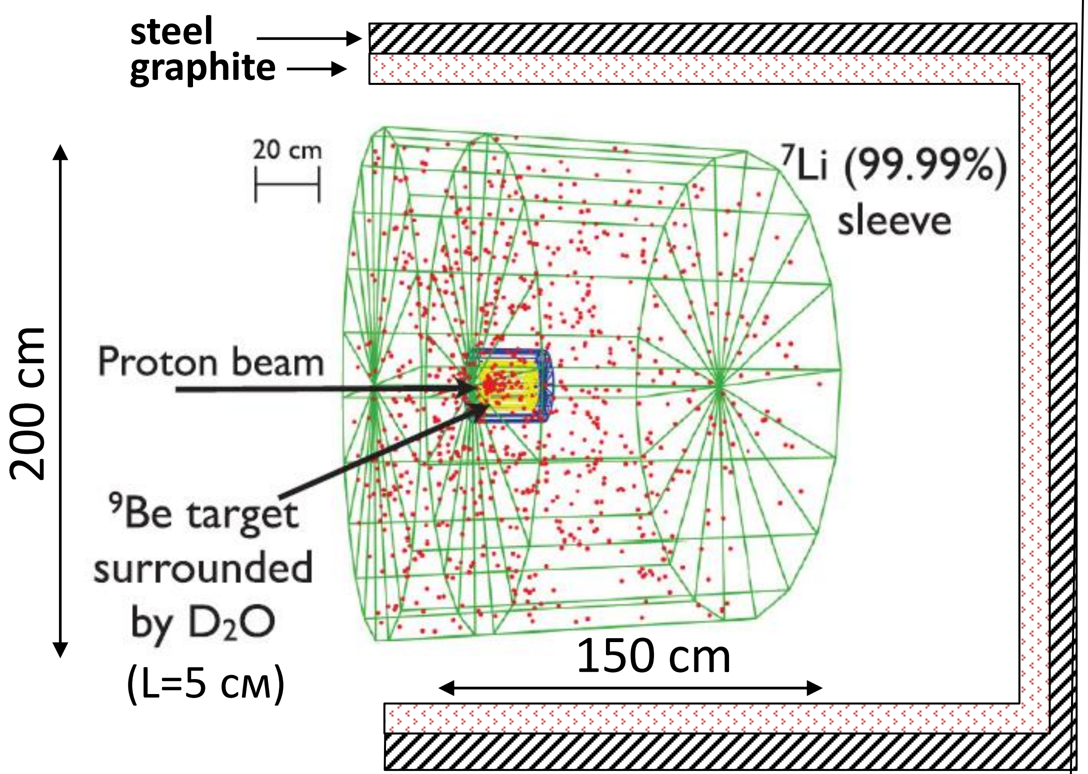
68% of created Li-8 nuclei are generated in the thin Li-7 metal layer (at R = < (22-27) cm).



Conclusion

- It is proposed an effective accelerator schemes for Li-8 antineutrino sources.
- The proposed for antineutrino sources (working in tandem with accelerator) ensure high Li-8 yield: ~ 0.13 Li-8 nuclei per proton (at proton energy Ep=200 MeV).
- The requested mass of high purified Li-7 (purification -0.9999) (and expensive at the high purification) can be decreased up to ~ 67.5 kg.
- The Li-8 antineutrino source can be very compact (~70 cm in length) that is exclusively important **for short base line** oscillation experiments.

Scheme of the Installation with Lithium Antineutrino Source (named as IsoDAR – Isotope Decay At Rest)



For realization of the IsoDAR project it will be requestsed 6.1 t of pure 7-Li (99.99% of purification).

Lithium antineutrino source IsoDAR

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Ep = 60 MeV, I=10 mA

-W = 600 kW

- Work cycle (time) – 90%

- Duration of the experiment – 5 years (in fact – 4.5 years)

-Yield – 14.6 antineutrinos/1000 protons (eficiency of 8Li production =1.46%)

-Expected yield of $\tilde{\nu}_e$ (for 5 years) - 1.29E+23

-The proposed detector – KamLAND

Distance from the target the detector center – 16 m

Expected statistic of the inverse beta decay (5 years) – 8.2E+5

Bungau A. et al. Proposal for an Electron Antineutrino Disappearance Search Using High-Rate 8Li Production and Decay // Phys. Rev. Lett. 2012. V. 109. P. 141802.

Thank you cordially for attention !