NEUTRON AND NEUTRINO OSCILLATIONS IN THE FRAMEWORK OF IFMIF/ELAMAT FACILITY

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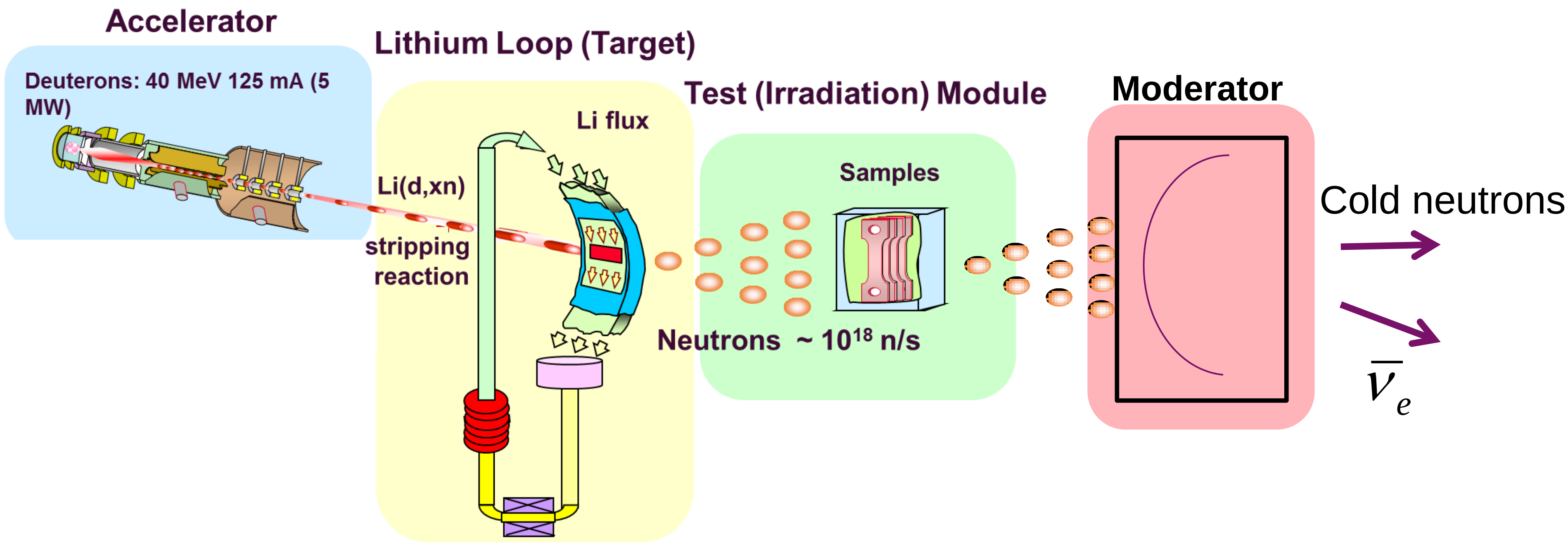
SCOPE



Why is there more matter than anti-matter in the universe?

→ neutron-antineutron oscillation

What is the nature of the neutrino?

→ neutrino oscillation

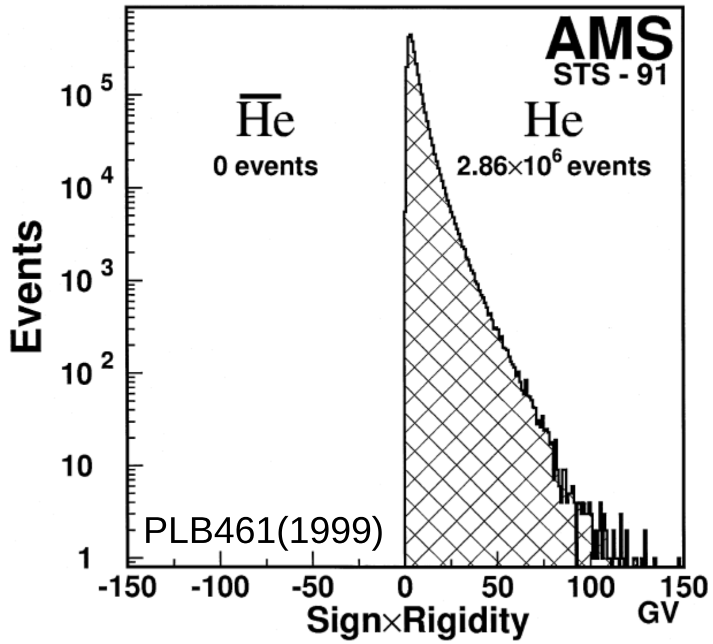
NEUTRON_ANTINEUTRON OSCILLATION

BARYON ASYMMETRY OF THE UNIVERSE (BAU)

Baryon asymmetry:

$$\eta = \frac{N_B - N_{\bar{B}}}{N_\gamma} \sim 10^{-10}$$

N_B number of observed baryon matter
$N_{\bar{B}}$ number of observed baryon anti-matter
N_γ number of photons (equivalent to entropy)



Sakharov's conditions to explain BAU

- **Baryon number violation →search for rare processes whith ΔB≠0**
- CP violation → observed in quark mixing but not sufficient for BAU
- Deviation from thermal equilibrium

BARYON NUMBER VIOLATION

Good reasons why baryon number should not be conserved

- Baryon (*B*) and Lepton (*L*) numbers conservations were introduced empirically in the Standard Model (no gauge term associated) to avoid some reactions (proton decay for example) but they are broken by non-pertubative effects (*B-L* is conserved)

- From neutrino oscillations we know that
  - L_e, L_μ and L_τ are not conserved.
  - Non zero masses for neutrinos are connected with *B-L* violation or existence of right-handed (sterile) neutrinos
  - Need of new physics above the SM
  - If neutrinos are Majorana (search in Double-Beta decay experiments), *L* is not conserved anymore ($\Delta L=2$)

- Baryon number is not conserved in most of the models above SM (supersymmetric models, GUT theories, …)

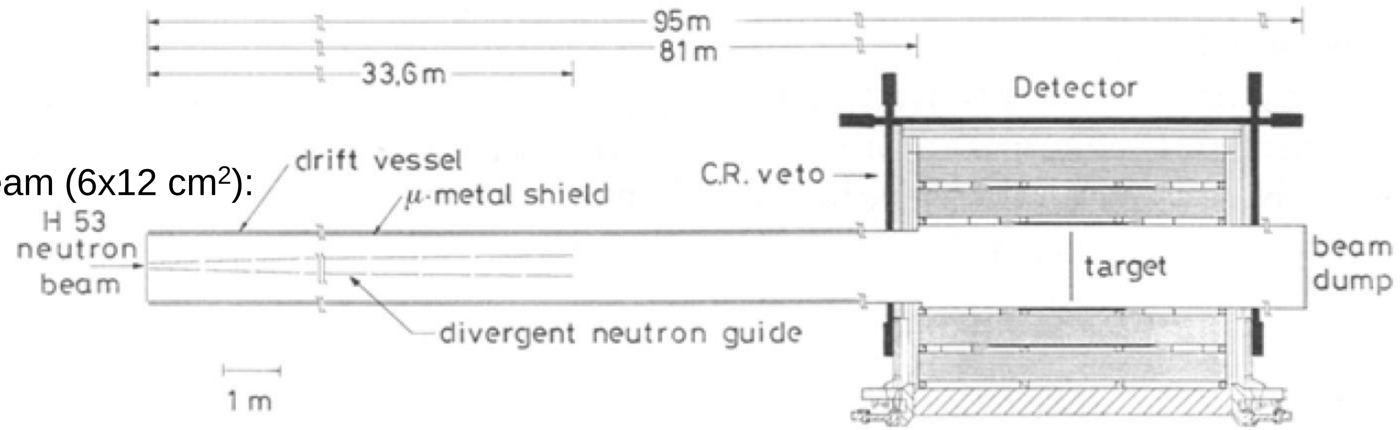
- since 2007 *Int. Workshop on Baryon & Lepton Number Violation*

HOW TO MEASURE N-NBAR OSCILLATION ?

Experimental Scheme for the previous ILL measurement

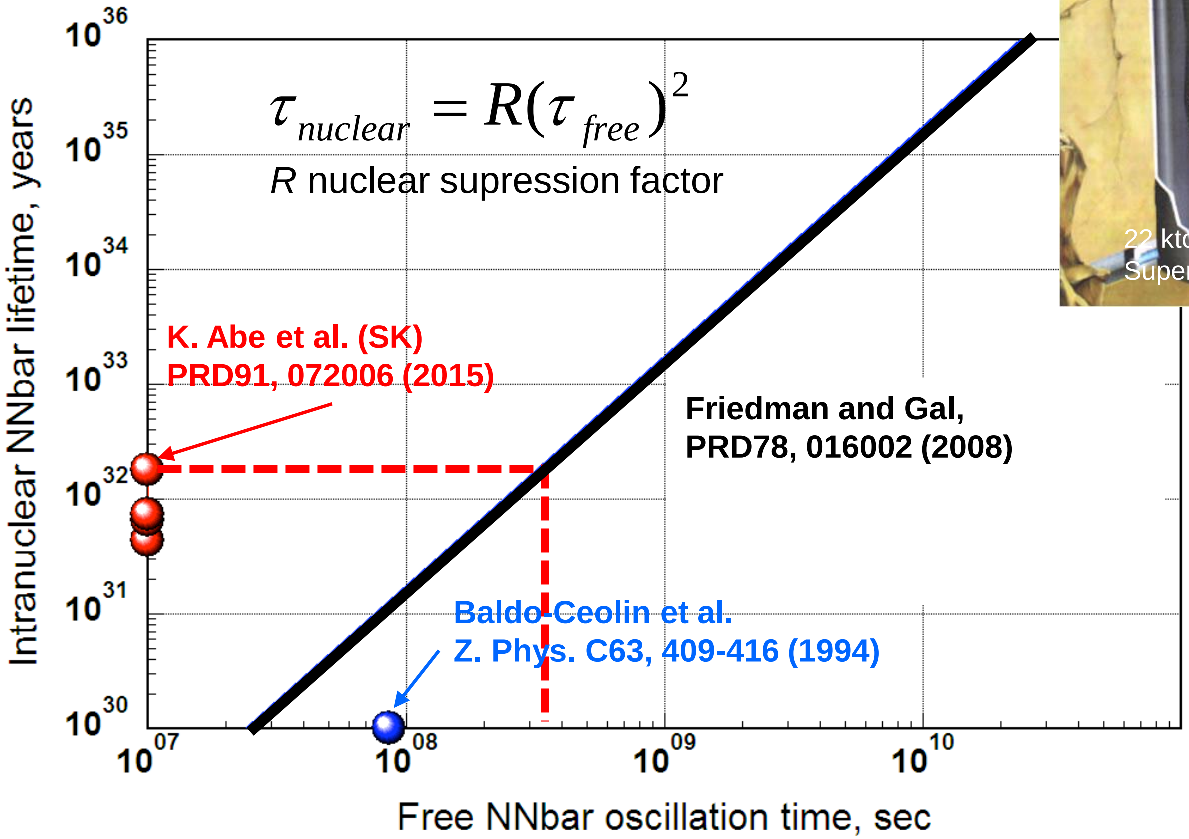
$\bar{n} + A \rightarrow <5>$ pions (1.8 GeV)

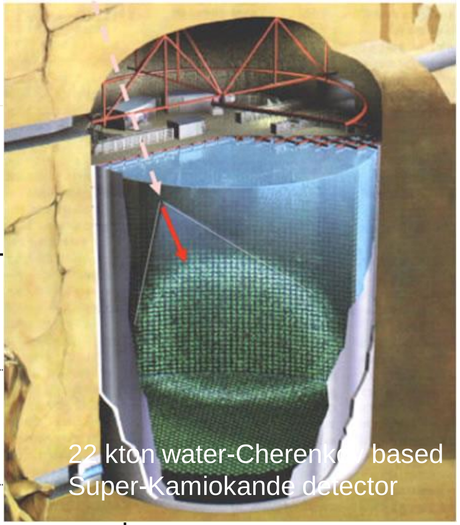
Cold neutron beam (6x12 cm^2):
~2 10^9 n/s/cm^2
$<v_n>$=600 m/s
1 year running



Baldo-Ceolin et al., Z. Phys. C63, 409-416 (1994)

- Bounded $n - \bar{n}$ oscillation in ^{16}O and ^{56}Fe nuclei
- Free $n - \bar{n}$ oscillation





HOW TO IMPROVE THE N-NBAR MEASUREMENT ?

$$P_{n\to\bar{n}}(t) = \frac{\delta m^2}{\delta m^2 + \Delta E^2}\sin^2\left(\frac{\sqrt{\delta m^2 + \Delta E^2}}{\hbar}t\right) \approx \left(\frac{t}{\tau_{n\bar{n}}}\right)^2$$

For quasi-free neutron:
$\Delta E \ll \delta m$
$t \ll \tau_{nn}$
$P<10^{-2}$ Pa and B< 10nT

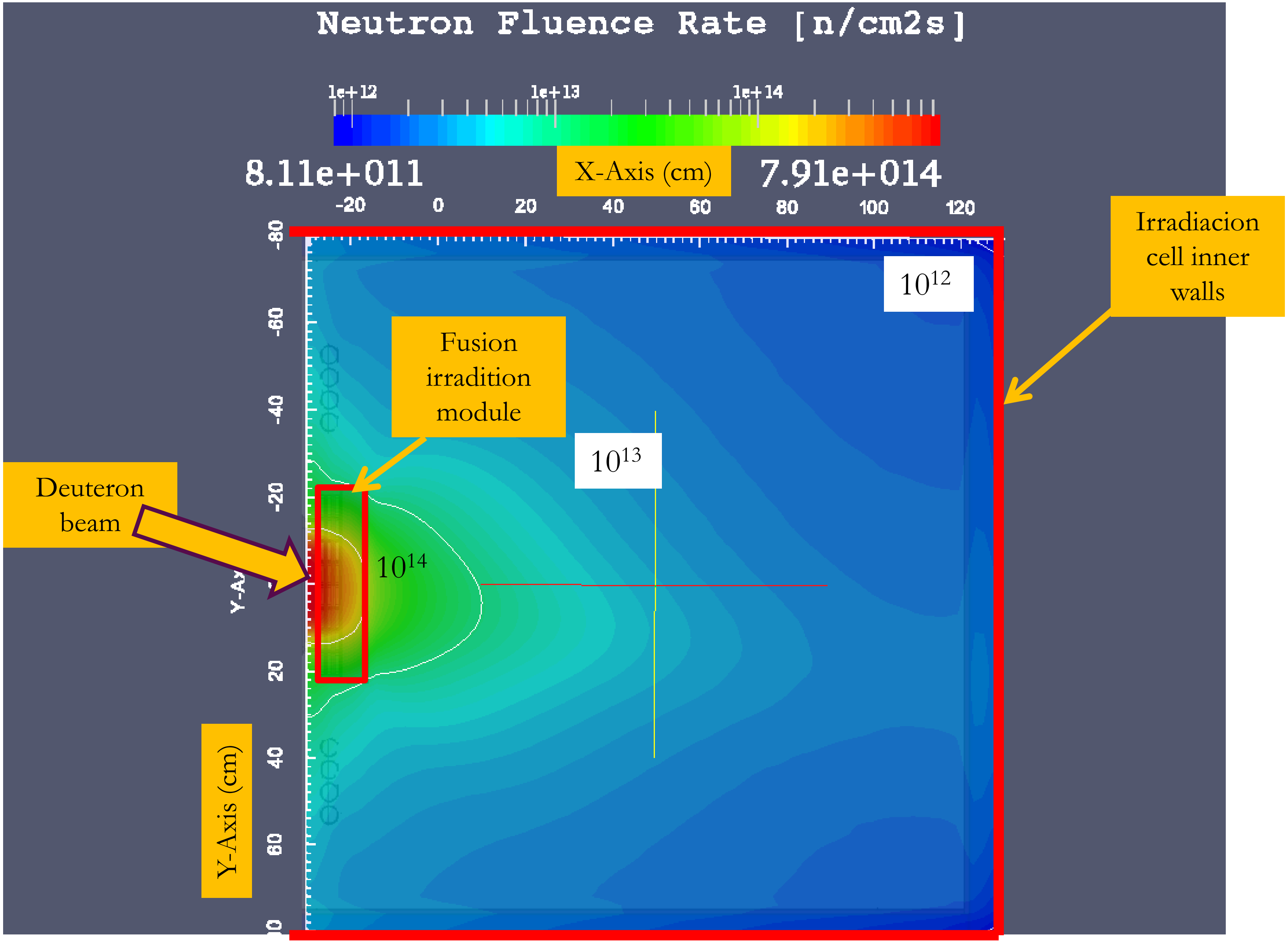
δm: the transition energy between the two neutron states
ΔE: the energy gap due to external field perturbations

$$FoM \approx N_n t^2$$

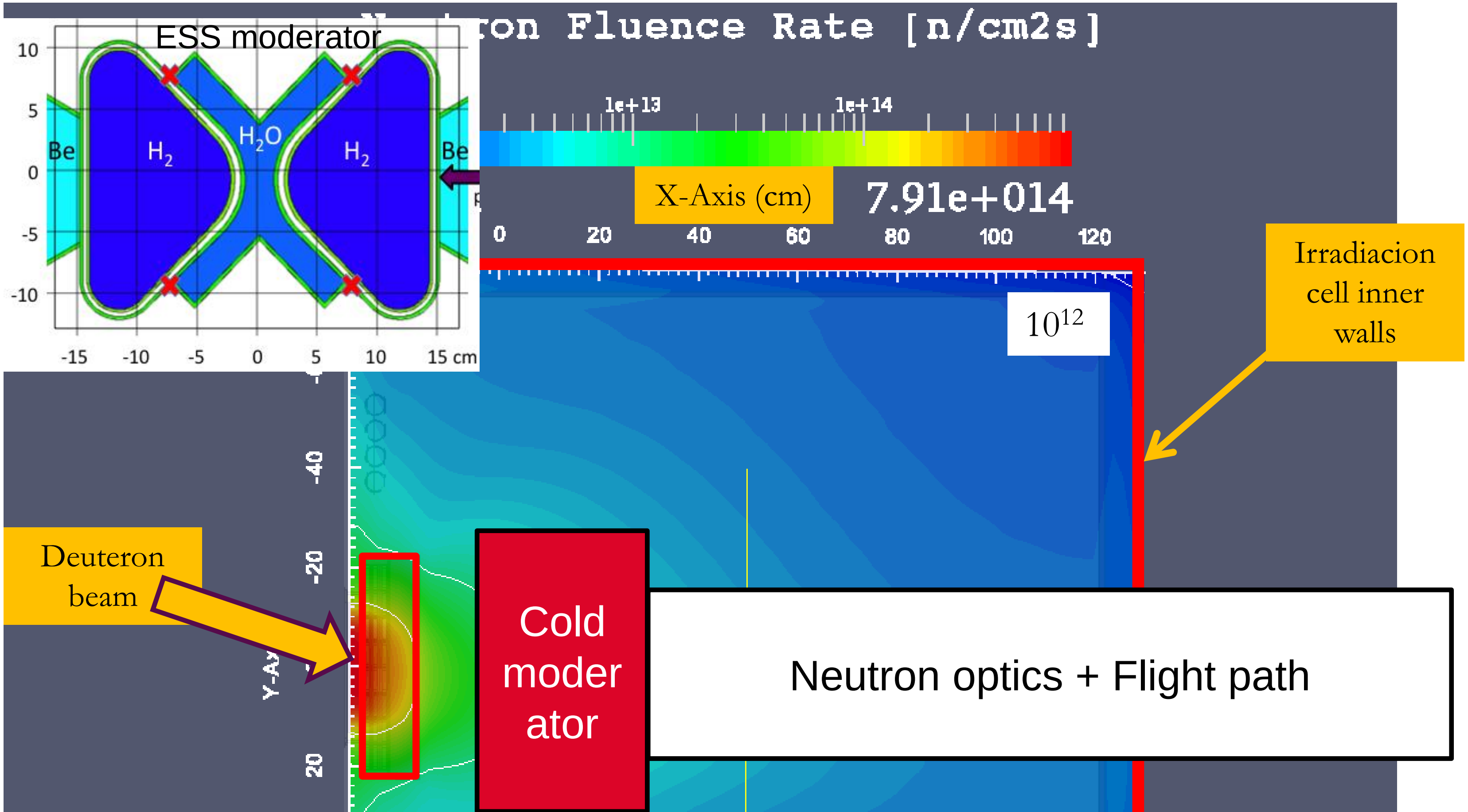
Number of neutrons / year on the target — Time spent in quasi-free conditions

- ✓ High brightness cold neutron source ($N_n > 10^9$ n/cm²/s)
  → high intensity accelerator based neutron sources like IFMIF
- ✓ Long flight path (> 76m) or lower neutron velocity (from cold to very cold neutrons)
  → improve moderator and neutron optics

N-NBAR IN THE IFMIF/ELAMAT CONTEXT



N-NBAR IN THE IFMIF/ELAMAT CONTEXT

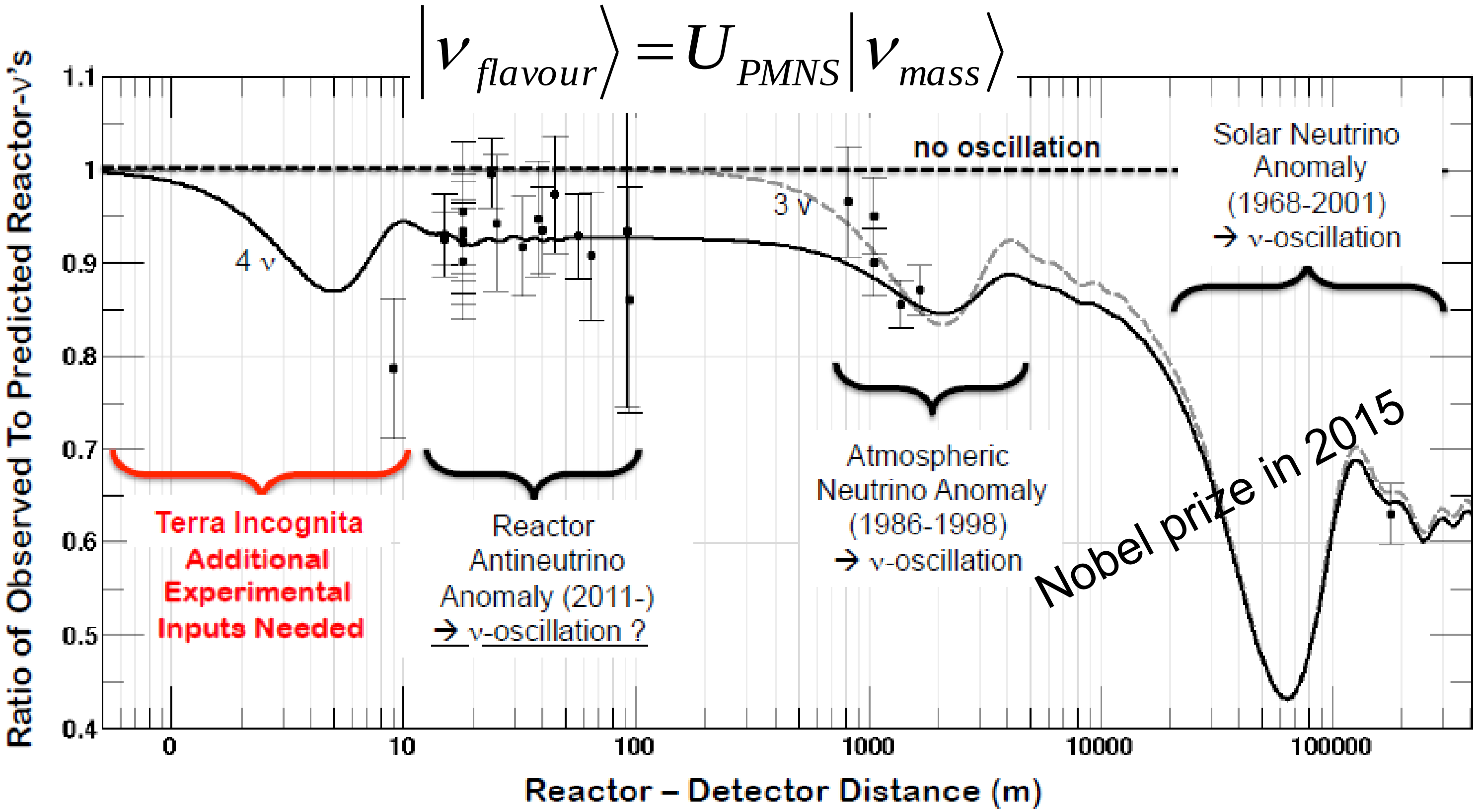


~10^{13} n/s/cm² compare to ~10^{9} n/s/cm² at ILL reactor (~10^{13} n/cm²/s at ESS)

- 10% of conversion with improved moderation techniques (para and ortho-H, cold Be reflector, cold nanoparticles…)
- improved focusing techniques (new supermirror, active focusing techniques,…)

NEUTRINO OSCILLATION

NEUTRINO OSCILLATION PICTURE



- Why the mass of the neutrinos so tiny ? → **existense of sterile states ?**
- CP violation in the lepton sector → related to BAU
- What is the mass ordering and absolute mass ?
- Dirac or Majorana nature ? → ΔL=2 lepton violation → related to BAU

THE ISODAR PROJECT

Proposal for an Electron Antineutrino Disappearance Search Using High-Rate ^{8}Li Production and Decay

A. Bungau[1], A. Adelmann[2], J.R. Alonso[3], W. Barletta[3], R. Barlow[1], L. Bartoszek[4], L. Calabretta[5], A. Calanna[3], D. Campo[3], J.M. Conrad[3], Z. Djurcic[6], Y. Kamyshkov[7], M.H. Shaevitz[8], I. Shimizu[9], T. Smidt[3], J. Spitz[3], M. Wascko[10], L.A. Winslow[3], J.J. Yang[2,3]

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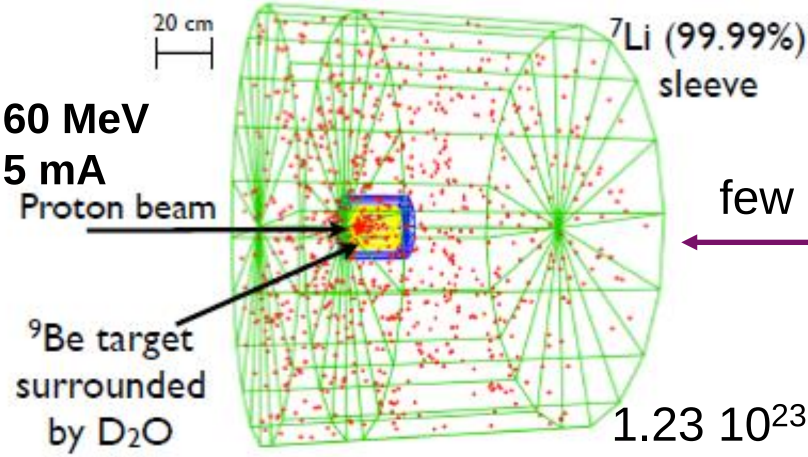
[10] Imperial College London, London, SW7 2AZ, United Kingdom

PRL109,141802 (2012)

$$^{7}Li + n \rightarrow ^{8}Li$$

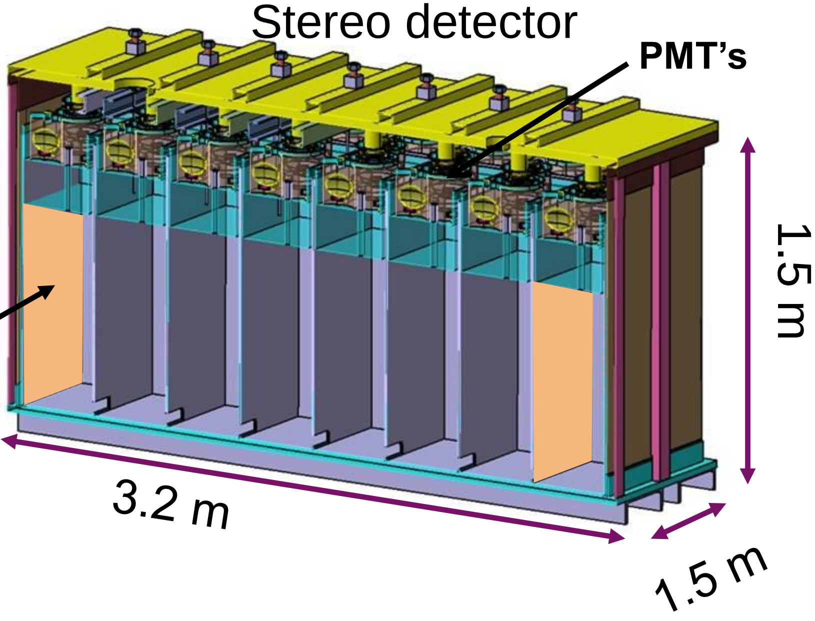
$$^{8}Li \rightarrow ^{8}Be + e^{-} + \overline{\nu}_{e}$$

60 MeV
5 mA

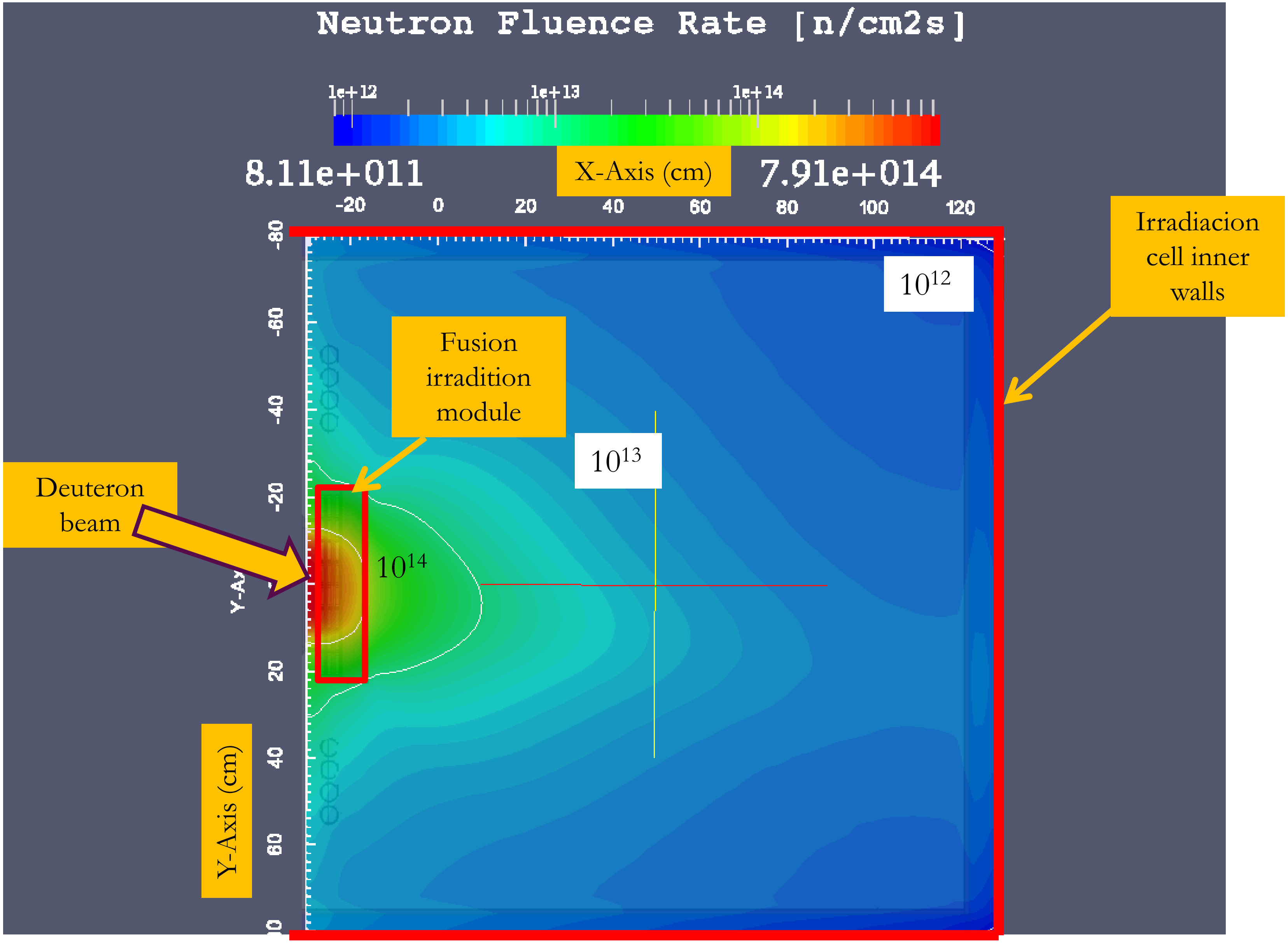


few meters

$1.23\ 10^{23}\ \upsilon_e$
(5 ans 90%cycle)



IFMIF/ELAMAT AS A NEUTRINO SOURCE



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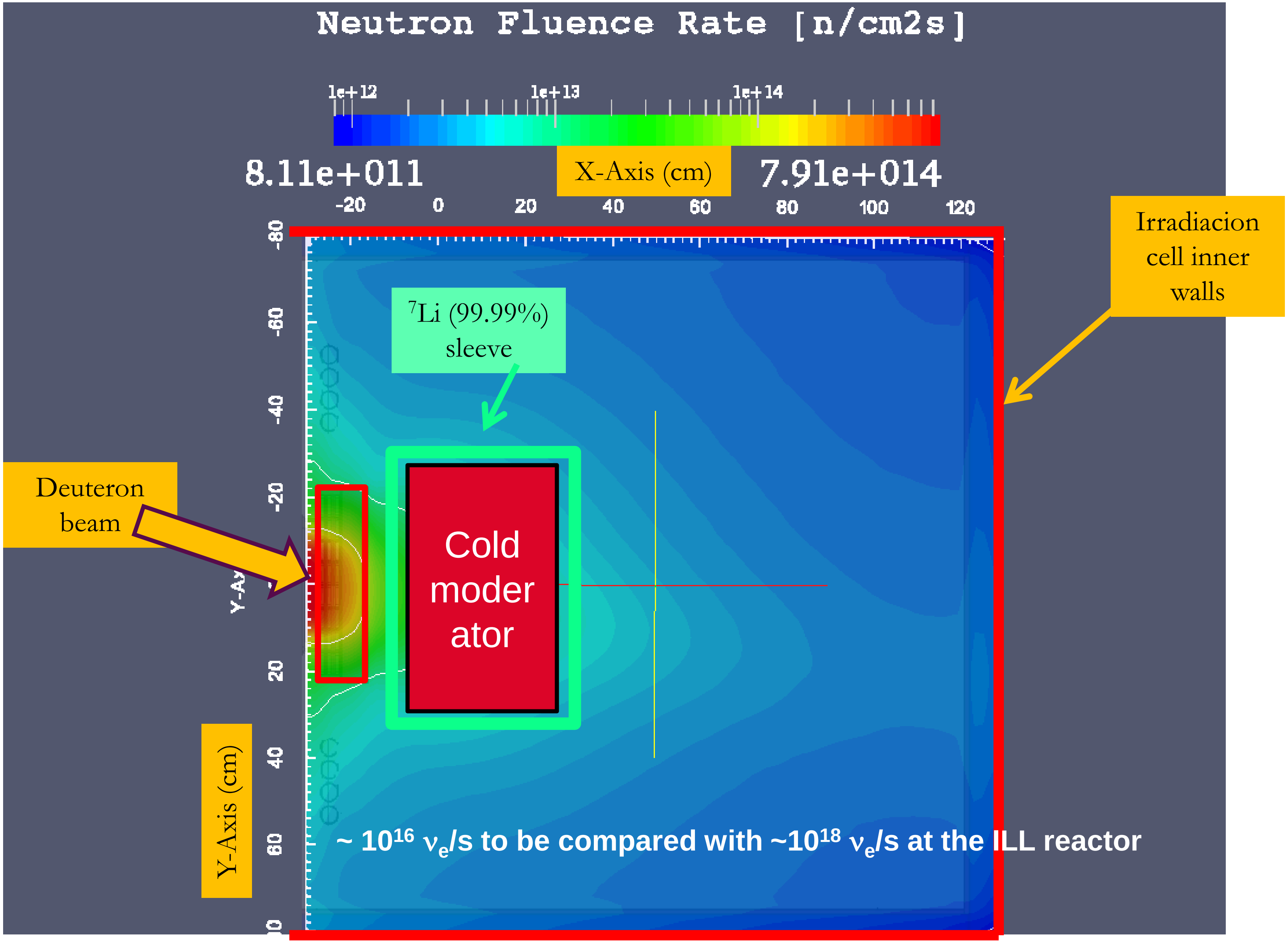

SUMMARY

- Neutron and Neutrino oscillations can bring new physics above the SM
- IFMIF/ELAMAT has potentialities to become a high brightness cold neutron source and β-decay at rest neutrino source
- Could open new opportunities for fundamental physics with cold neutrons (search for n-EDM, neutron beta-decay studies, ….) and neutrinos (short-range oscillations, cross sections, ….)
- Dedicated studies have to be done to evaluate these capacities