Production of ultracold neutrons in a decelerating run away trap

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Production of UCNs

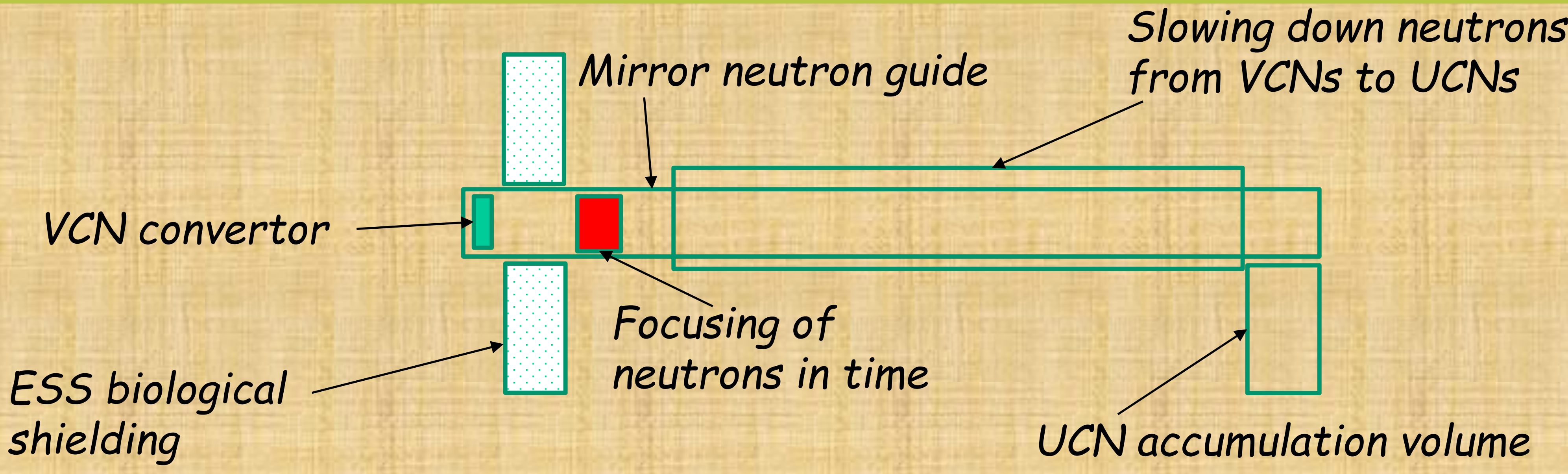
- Discovered by extracting a tiny fraction, 10^{-11}, from a broad **equilibrium spectrum of thermal neutrons** [V.I. Luschikov et al, JETP Lett. 9 (1969) 23; A. Steyerl, Phys. Lett. 29 (1969) 33],

- Equilibrium cooling in a **cryogenic moderator**. Liquid deuterium UCN source at ILL [P. Ageron, NIMA 284 (1989) 197; A. Steyerl, Phys. Lett. A 116 (1986) 347],

- **Non-equilibrium interaction** of thermal and cold neutrons with **solid deuterium** or **liquid helium** [R. Golub, J.M. Pendlebury, Phys. Lett. A 53 (1975) 133].

A common feature of all the sources and projects is the **huge difference** between the designed and obtained UCN density… An important reason, apparently, is the **difficulty in extracting** the produced UCNs from the source.

Description of proposed the method



The VCN converter is installed in the region of the **maximum neutron flux** in the neutron source and might be surrounded on all sides, except for the direction of VCN extraction, by a **nano-diamond reflector**, transparent to thermal and cold neutrons, but completely reflecting VCNs.

The principle of operation and features of each of these devices are explained in the following transparencies.

Description of proposed the method

Most of these ideas have been **proposed or used** before:

- The principle possibility of achieving UCN densities in phase space **approaching the peak one in a convertor** in a pulsed neutron source was proposed by F.L. Shapiro [Ф.Л. Шапиро, ЭЧАЯ 2 (1972) 973],
- Selection of the **optimal range of the initial phase space** is the basis of the Steyerl turbine method [A. Steyerl, NIMA 125 (1975) 461],
- **Focusing of neurons in time** was proposed by A.I. Frank and R. Gaehler [A.I. Frank, R. Gaehler, Phys. At. Nucl. 63 (2000) 545],
- **The motion of neutrons together with a material trap** was experimentally demonstrated by A.V. Strelkov [B.V. Bagrjanov et al, Phys. At. Nucl. 62 (1999) 787; V.K. Ignatovich et al, Phys. At. Nucl. 65 (2002) 2029],
- **The deceleration of neutral particles** by an inhomogeneous magnetic field is actively used [N. Vanhaecke et al, Phys. Rev. A 75 (2007) 031402], etc

Deuterium convertor

The design kindly provided by Luca Zanini

The proposal:

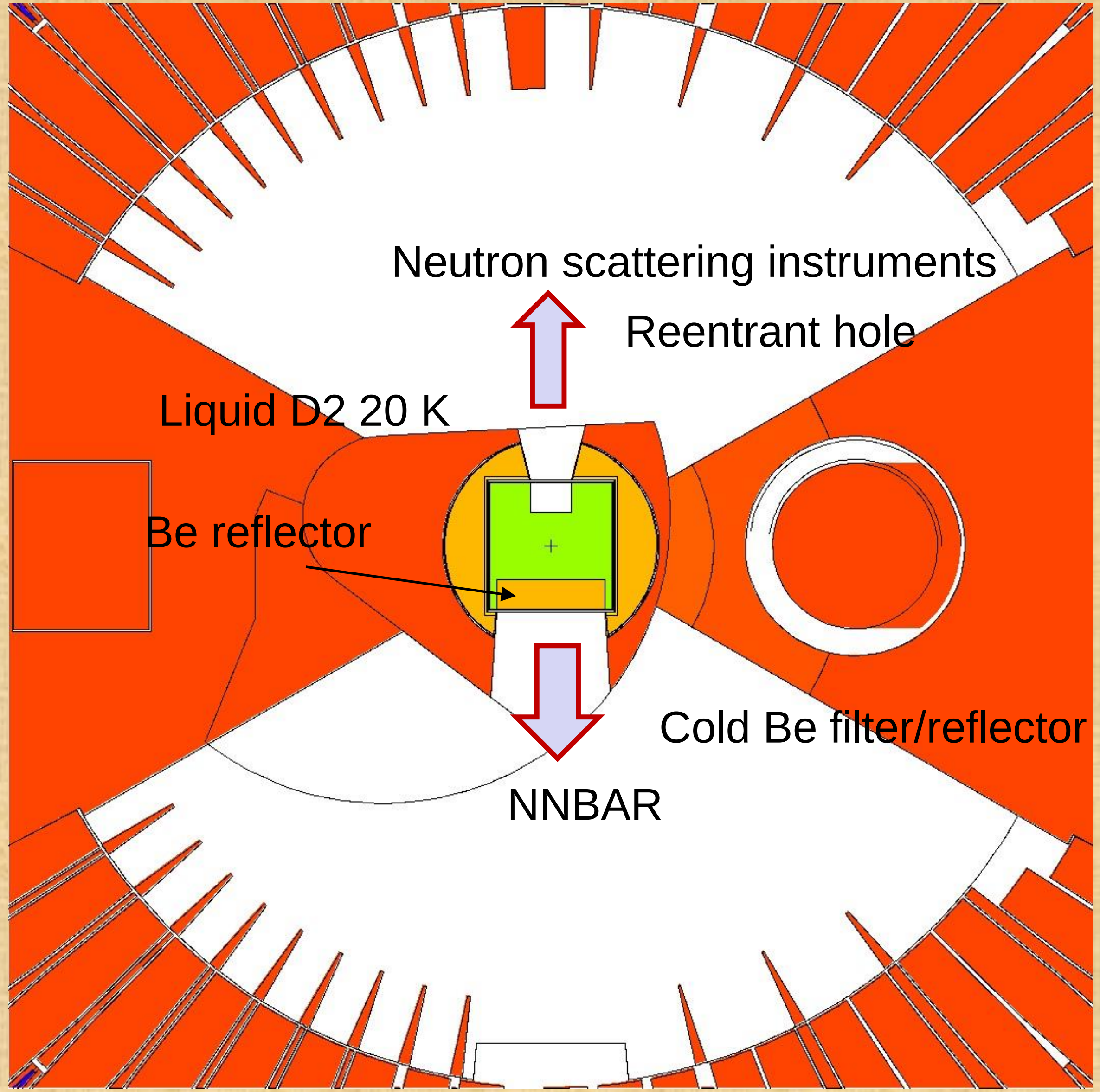
to replace

Be reflector by

solid-deuterium

VCN converter,

Or to put on top of the reflector



Deuterium convertor

Solid deuterium has been well studied theoretically and experimentally as a **UCN convertor** [tens of references and the great experience of my colleagues present at this workshop]

Its use also as a **VCN converter** seems natural.

Uncertainties associated with UCN rescattering by deuterium density inhomogeneity, which are critical for large suppression of the efficiency of UCN extraction, are **insignificant for VCNs**.

Within the framework of the CREMLIN+ project, we will study the generation of VCNs in solid deuterium surrounded with a nano-diamond reflector, both **theoretically and experimentally**.

A characteristic extraction depth is **~10 cm** (the convertor thickness might be smaller if the **nano-diamond reflector** used)

A guide with the decelerating trap

The running away decelerating trap can be based on:

- *Reflection of neutrons from a **material surface** (an empty Pepsi-Cola can without a lid or only a flat lid + a mirror neutron guide),*

- *Reflection of neutrons from a **magnetic field gradient** (methods of pulsed magnetic fields from current in copper conductors, possibly cooled to the nitrogen temperature).*

A combination of these two methods is possible.

Focusing of neutrons in time

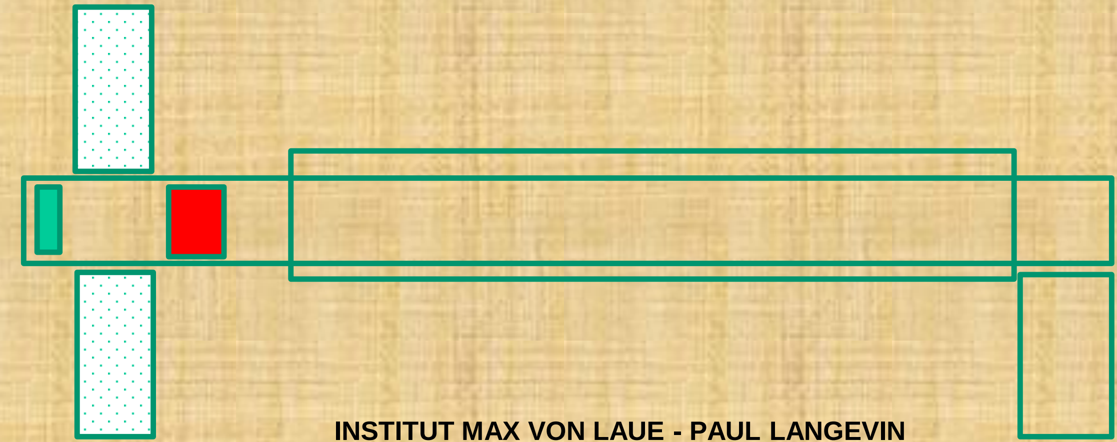
Let the initial velocity of VCNs be **~50 m/s** *(for the efficient extraction of neutrons with low losses),*

Let the neutron guide length inside the biological scielding be **~5 m***),*

The VCN spread along this section of the guide would be **~1.2 m** *(much larger than the VCN convertor size/depth),*

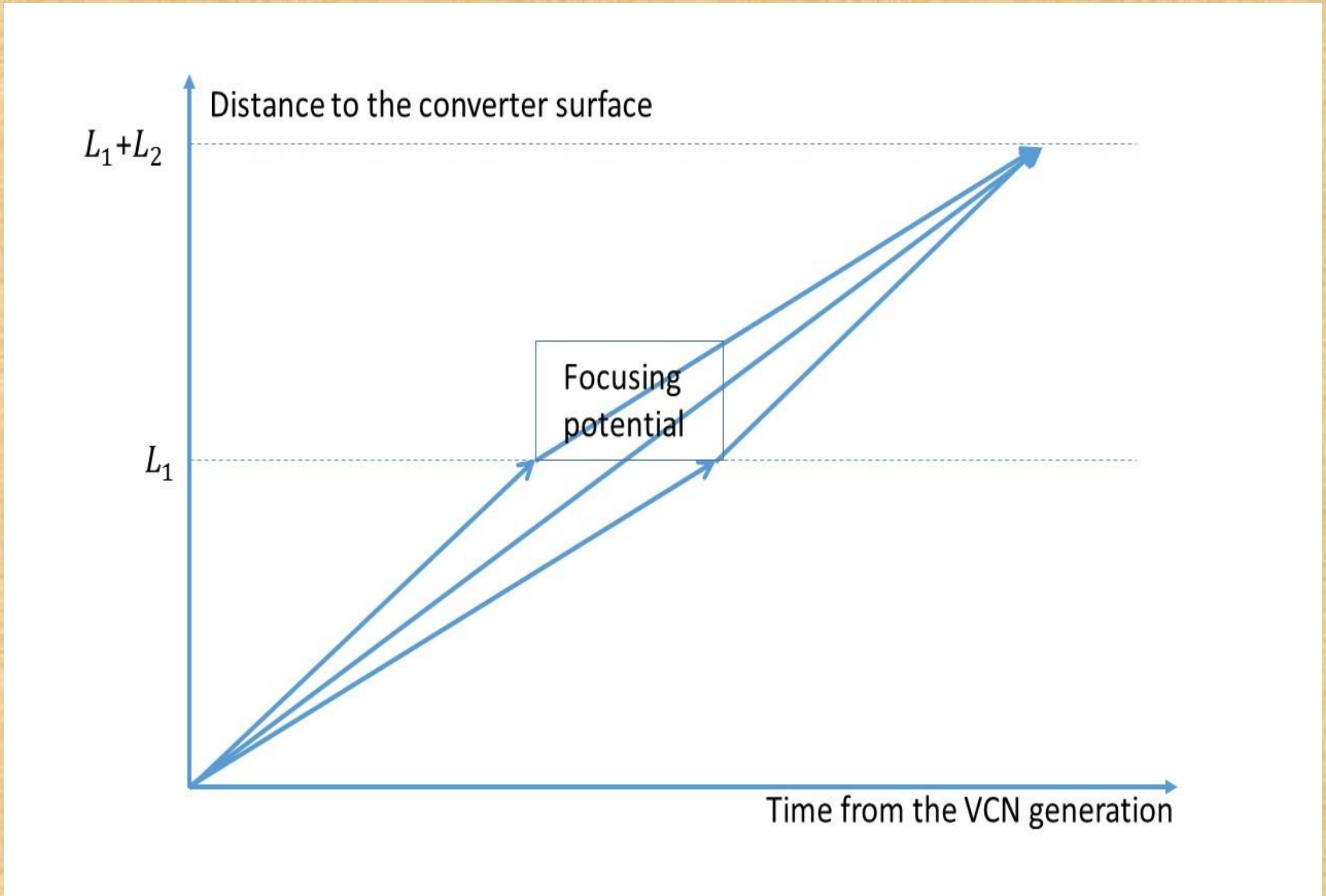
But we ***know*** *where the VCNs will be at each velocity at any moment of time,*

Therefore the neutron ***density in phase space is not lost*** *!!*



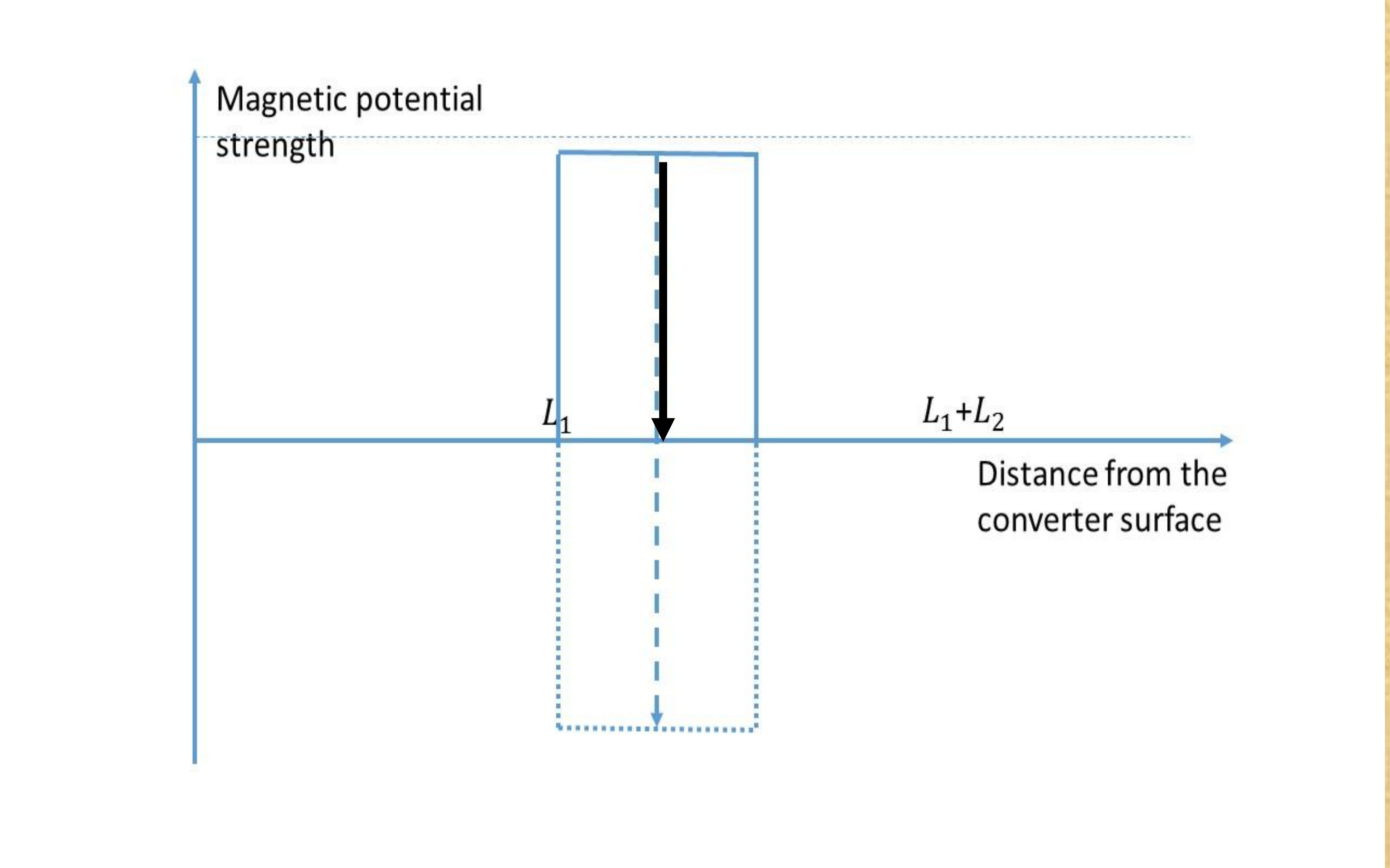
Focusing of neutrons in time

A principle scheme of neutron focusing in time



Focusing of neutrons in time

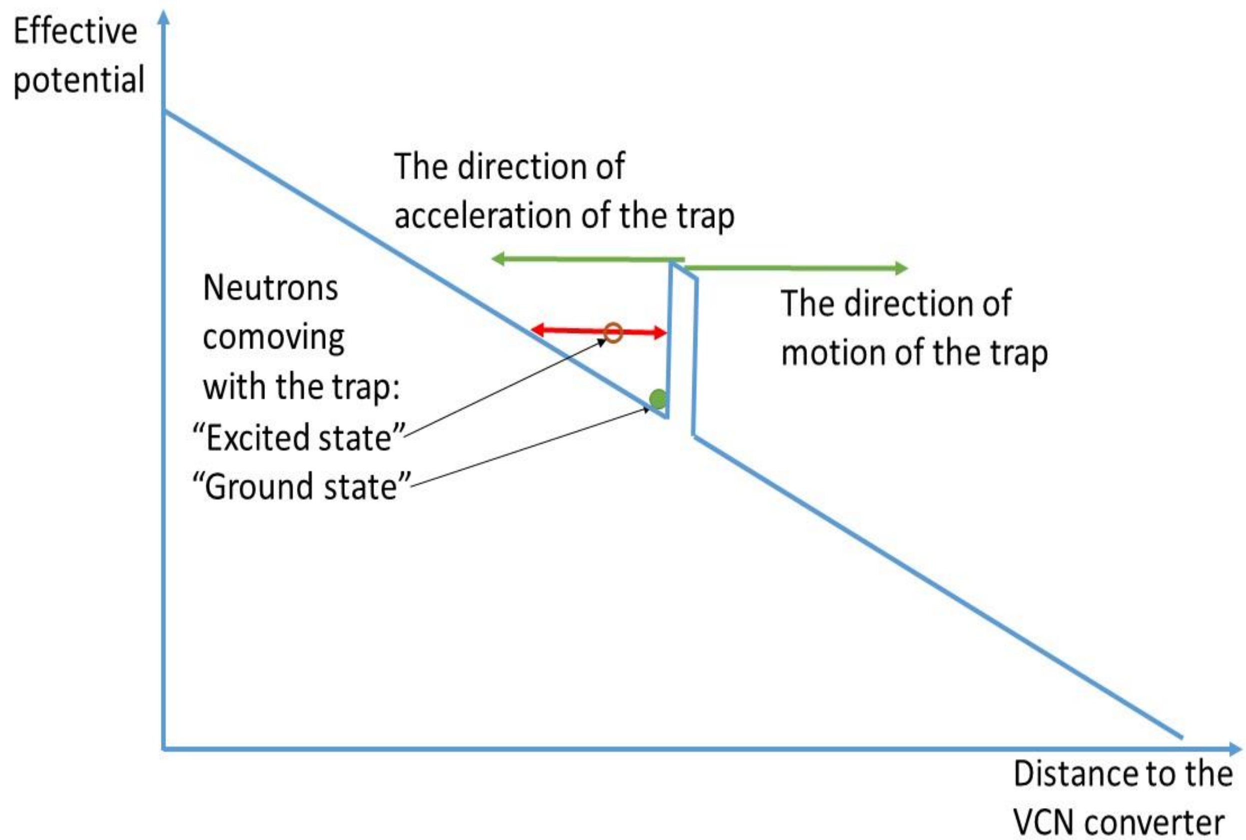
A focusing device based on the ***magnetic field****: while the VCN flew this distance, the potential –* ***uniformly in space*** *– decreased to a negative value*



Deceleration together with the trap

The wall raising is non-adiabatically fast (compared to ***10 ms****)*

The pulse magnetic field is ***2.5 Tl***



Effective potential trapping the neutron bunch *in the coordinate system associated with the escaping slowing down trap*

Deceleration together with the trap

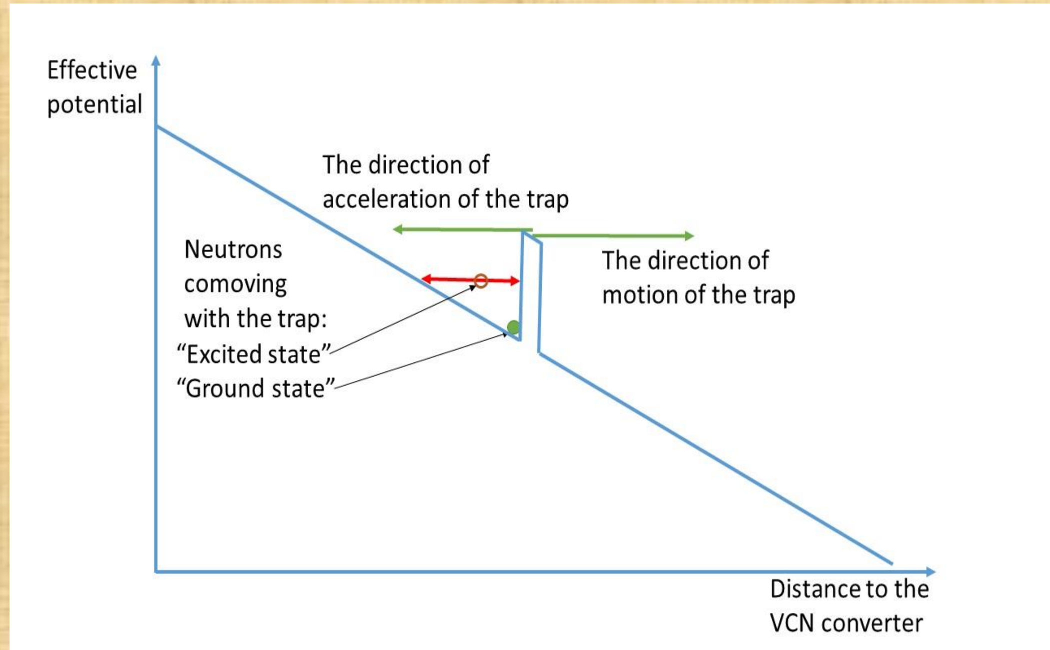
For a neutron located at the **bottom of the potential well**: it does not move in the coordinate system associated with the trap, but in the laboratory coordinate system it **slows down with a constant acceleration**.

The trap can slow down neutrons of **ANY** initial velocity.

The height of the walls of the trap can be **ARBITRARY LOWER** than the initial energy of the neutron.

A neutron in an excited state in the potential well oscillates. In the accelerator terminology, this is **autofocusing**!

Acceleration **10 g**, field **0.17 Tl/cm**, deceleration length **22.5 m**, a few "traps" simultaneously



Accumulation of many bunches (~0.3 m^3)

A fast valve with a characteristic time of **<20 ms**,

It is open only ***during each UCN bunch arriving***,

It is located at the end of the decelerating zone, i.e., far from the ESS source, in an ***accessible place***

A broader initial spectrum?

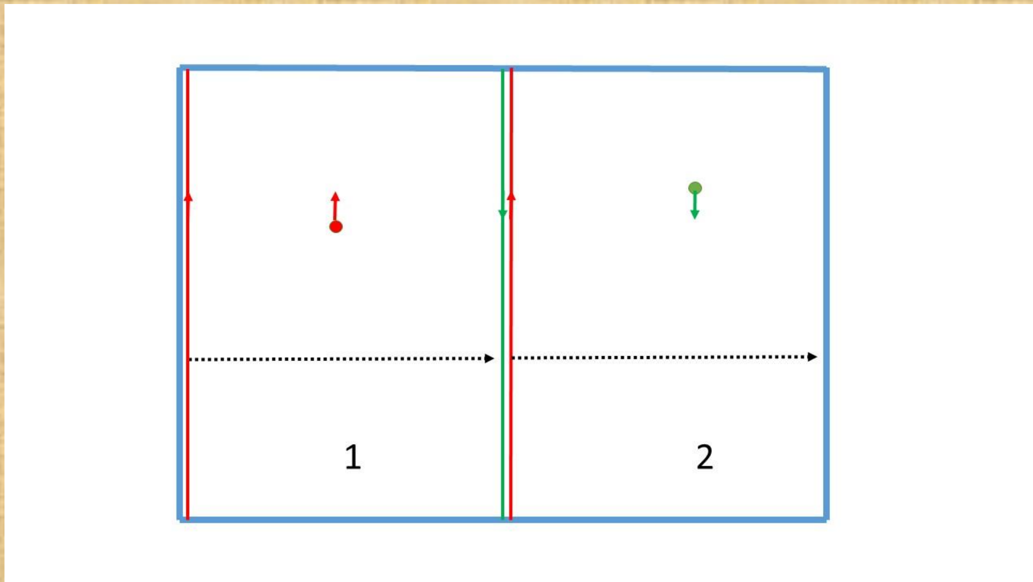
Increases the ***total amount*** *of produced UCNs, i.e., the volume that can be filled with UCNs with* ***the same phase-space density***.

This requires an ***increase in currents and magnetic fields****, which are already very large…*

Doubling the density

*A principle possibility of increasing the UCN density due to the addition of UCNs with **opposite polarizations** in the same volume,*

This might be possible but has never been verified



Acceleration of UCNs…

*The possibility of producing **monochromatic** neutrons with a high phase-space density*

In principle, it is possible to produce neutrons of any velocity with the same phase-space density as the initial one. This is of interest if one can build a standing alone UCN source