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21.4
On the Possibility of Direct Investigations of Neutron-Neutron Scattering at LHC Beam Dump

A.V.Dementiev, D.V.Dementiev, M.V.Kazarnovsky, V.A.Matveev,
V.G.Miroshnichenko, S.A.Novoselov, N.M.Sobolevsky, S.F.Sidorkin
Y.Y.Stavisski*)
Institute for Nuclear Research RAS, 117312 Moscow, Russia

Periodic cleaning of the main ring of LHC by one-turn extraction of the stored protons on the gives the possibility to generate the giant pulses of slow neutrons in ring-shaped target-moderator assembly, inserted into head part of the graphite beam-dump. The evaluation of the peak thermal neutron density gives the value ~ $1.5\text{x}10^{19}$ neutr/cm^{2}s for hydrogen containing moderator. This opens the unique possibility for the direct measurements of n-n scattering length by registering neutrons, scattered in the vacuum cavity inside this moderator.

1. Introduction

According to the hypothesis of the charge independence of nuclear forces, the interaction of the two nucleons in the same quantum states should be equal. In particular, at low energies neutron-neutron scattering lengths in the state with isospin T = 1 and spin S = 0 should be equal, i.e.

$$^1a_{pp} = {}^1a_{np} = {}^1a_{nn}$$

The np- and pp-scattering were measured many times. Taking into account the corrections for Coulomb interaction, interaction between magnetic moments, the difference of neutron and proton masses, the vacuum polarization and finite sizes of nucleons [1-4], the singlet scattering length are equal:

$$^1a_{np} = (-\ 23.516 \pm 0.013)\ \text{fm}$$
$$^1a_{pp} = (-\ 17.25 \pm\ 0.16)\ \text{fm}$$

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*) Correspondent author. E-mail: stavs@t-online.de

About 50 indirect measurements of nn-scattering length are known. They are based on studying the influence of two flying neutrons on the C-particle energy spectrum in reaction A + B → C + 2n. The obtained values are ranged within

$$-11.2 \text{ fm } [5] > {}^1a_{nn} > -25 \text{ fm } [6]$$

The scattering length averaged over the published data is presented in work [7]:

$${}^1a_{nn} = (-16.70 \pm 0.38) \text{ fm}$$

With increasing the accuracy, some experiments reveal a divergence in a measured value of ${}^1a_{nn}$ in different reactions.

Thus, apparently ${}^1a_{np}$ noticeably differs from ${}^1a_{nn}$ and ${}^1a_{pp}$. And if the difference $\Delta a = |{}^1a_{np} - {}^1a_{nn}| \sim 7$ fm can be explained by indirect electromagnetic processes (mass difference of charged and neutral π^- and ρ mesons), the question about character of the difference between ${}^1a_{nn}$ and ${}^1a_{pp}$ is still open as the estimates of the both values are rather uncertain.

The successes in elementary particles physics achieved recently enables one to hope that within the framework of the up-date theoretical models the different strong interaction characteristics at low energies (see, for example [8]), in particular, difference between ${}^1a_{nn}$ and ${}^1a_{pp}$ could be estimated accurately. In this case, by measuring ${}^1a_{nn}$ we can compare the different theoretical models.

The experiments on low-energy nn-scattering were proposed many times. Moravcsic [9] proposed to use the nuclear explosion. Also, there was discussed the possibility of using a nuclear reactor in space [10], as well as a pulsed reactor IBR-2 [11]. A detailed analysis of the possibility for performing such experiment with high-flux and pulsed reactors [12,13] shows that the main problem is the suppressing of the background of fast and delayed neutrons.

In [14] discussed the possibility of direct measurement of ${}^1a_{nn}$ at the Moscow Meson Facility. An advantage of using the thick lead target of meson facility as a pulsed neutron source is the low intensity of fast (delayed) neutrons between pulses. It give the possibility to eliminate by time selection the flux of fast (delayed) neutrons and to decrease sufficiently the corresponding background.

2. Giant neutron pulses in beam dump LHC

The creation accelerator-storage complex LHC (fig. 1) opens up the unexpected capabilities for physical research in pulsed fluxes of low-energy neutrons with extra high density (thermal, cold and ultracold) [15]. Here are discussed the experiments with thermal (~300K} neutrons. Possible experiments with cold and ultracold neutrons are in stage of estimations and discussions.

According [16] the main LHC mode provides acceleration and storage of $\sim 3.10^{14}$ protons with energy 7 TeV and one-turn extraction of the full intensity into graphite beam dump every 10 hours in consequence of loss of the luminosity in interaction points due the beam spread. The Conceptual Design [16] calls for corresponding kiker- and septum magnets and special spreading system that give the possibility to form ring-shaped beam at entrance into graphite beam-dump [15], fig. 3.

If one inserts into the initial part of the graphite beam dump the ring-shaped heavy target (f.e. tungsten) with inner hydrogen-contained moderator, in the moderator will be generated the high density pulsed flux thermal neutrons. The diffusion time of thermal neutrons in light hydrogen-contained moderator is close to the protons revolution time in main ring LHC and, corresponding, emission time of spallation neutrons. It is the base for a generation giant pulse of thermal neutrons with relative short duration. Our calculation performed using original NeuMC code for moderation and thermal neutrons diffusion in light water (or zirconium hydride) gave peak flux density of thermal neutrons in cavity ~ $1.5.10^{19}$ neutr/cm^2s at pulse duration ~ 120 mcs and using only 10^{14} protons per cycle. This limited by heating the target in pulse. The specific neutron yield for 7 TeV protons and heavy target (W, Pb) - ~ 2.5 neutr/pGeV [17] was estimated by using FLUKA [18] and CALOR [19] codes.

3. Principal scheme of the Neutron-Neutron scattering experiment

A principal scheme of thermal neutrons nn-scattering experiment with pulsed neutron source based on spallation process (fig.2) is similar the Moscow Meson Facility proposal [14]. The neutron source is the Mo-, Zr-, W- or ^{238}U-target irradiated by pulsed proton beam from storage ring. Close to the target 1 is arranged the moderator 2 with a cylindrical hole (cavity) being part of vacuum volume. Vacuum volume is restricted by back wall 3 and detector 4. The detector is isolated with system of collimators and diaphragms 5 absorbing thermal neutrons such it does not "see" the moderator and vacuum chamber surfaces. Therefore, under ideal condition it can detect only those neutrons which are scattered inside vacuum volume in region big flux.

The main background sources in the experiment are the following:

1) Fast neutrons from target (if the detector is switched off during spallation neutrons pulses) this background caused only by delayed fast neutrons. This neutrons is connected with fission in target. It is known that fission is proportional ~ Z^2/A, the neutron yield ~ A, then "signal/noise" ratio is proportional ~ A/Z^2. Therefore it is interesting using the relative light targets.
2) Thermal neutrons scattered from edges of collimators as well as from vacuum chamber walls (manly from back wall).
3) Neutrons scattered by residual gas in vacuum volume. This background is proportional to residual gas pressure and peak flux neutron density. At high neutron density possible to use relative "bad" vacuum.
4) Cosmic neutrons background.

4. Neutron-Neutron scattering at LHC

Taking into account the possible conditions for the nn-scattering investigations at LHC we have chosen the following scheme of the experiment. The neutron source is a tungsten ring-shaped target with inner zirconium-hydride moderator ~ Ø30 cm x 60 cm with vacuum hole Ø20 cm and vacuum $\leq 10^{-7}$ Torr. The distance between the center of target-moderator assembly (TMA) and outside surface of the iron-water shield is ~ 11 m towards detector and ~ 9 m towards vacuum chamber back wall. The distance between center TMA and back wall of the vacuum volume ~ 25 m, up to detector ~ 12 m. It used three collimators on distance 2, 4 and 6 m from TMA, consist from iron-water and boron-carbide layers and have thickness 100, 150 and 180 cm correspondingly, the trap Ø100 cm. In collimators located cadmium diaphragms and coatings. Detector diameter - 22 cm, the diameter the back-wall "spot" from which neutrons can reach detector - 80 cm.

5. Results of calculations

After a pulse beginning the detector is switched off during ~ 3 ms (for decreasing the background from the fast and epithermal neutrons). In this case all neutrons with energy E_n>0.84 eV emitted by TMA and neutrons with energy E_n>2.2 eV reflected from back wall are "time-selected". At the same time about 70% of events of nn-scattering are detectable.

Under indicated parameters of the assemble the thermal neutron flux through detector will be ~ 10^5 neutr/pulse. The background of thermal neutrons scattered from edges of collimators as well as from vacuum chamber walls is ~ 1 % of this effect. The backgrounds of thermal neutrons, scattered by residual gas with a pressure P ~ 10^{-7} Torr is ~ 6 %. The background of delayed fast neutrons my be neglected. The background of cosmic neutrons (from cosmic muons) is << 1% of the effect. The estimation show that for a measurement of nn-scattering lengths with an accuracy ~ 1% sufficient ~ 3 giant pulses, including the background and correction experiments.

6. Conclusion

The calculation of spallation neutrons yield, moderation and diffusion of neutrons in target-moderator assemble of special beam dump LHC, evaluation neutron-neutron scattering in vacuum cavity and accompanied backgrounds give the hope for direct measurement the nn-scattering length with high accuracy (~ 1%).

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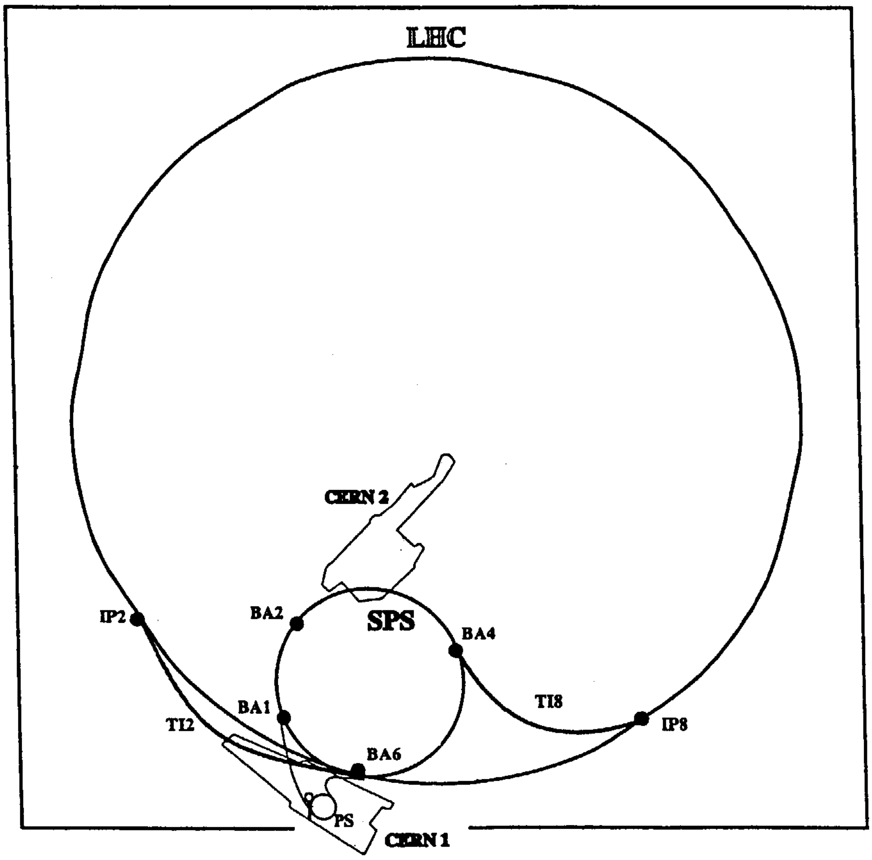

Figure 1: SPS–LHC transfer lines

Energy	E	[TeV]	7.0
Dipole field	B	[T]	8.4
Luminosity	L	[$\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$]	10^{34}
Beam–beam parameter	ξ		0.0034
Total beam–beam tune spread			0.01
Injection energy	E_i	[GeV]	450
Circulating current/beam	I_beam	[A]	0.53
Number of bunches	k_b		2835
Harmonic number	h_RF		35640
Bunch spacing	τ_b	[ns]	24.95
Particles per bunch	n_b		$1.05\ 10^{11}$
Stored beam energy	E_s	[MJ]	334
Normalized transverse emittance $(\beta\gamma)\sigma^2/\beta$	ϵ_n	[μm.rad]	3.75
Collisions			
β-value at I.P.	β^*	[m]	0.5
r.m.s. beam radius at I.P.	σ^*	[μm]	16
r.m.s. divergence at I.P.	σ'^*	[μrad]	32
Luminosity per bunch collision	L_b	[cm^{-2}]	$3.14\ 10^{26}$
Crossing angle	ϕ	[μrad]	200
Number of events per crossing	n_c		19
Beam lifetime	τ_beam	[h]	22
Luminosity lifetime	τ_L	[h]	10

fig. 1

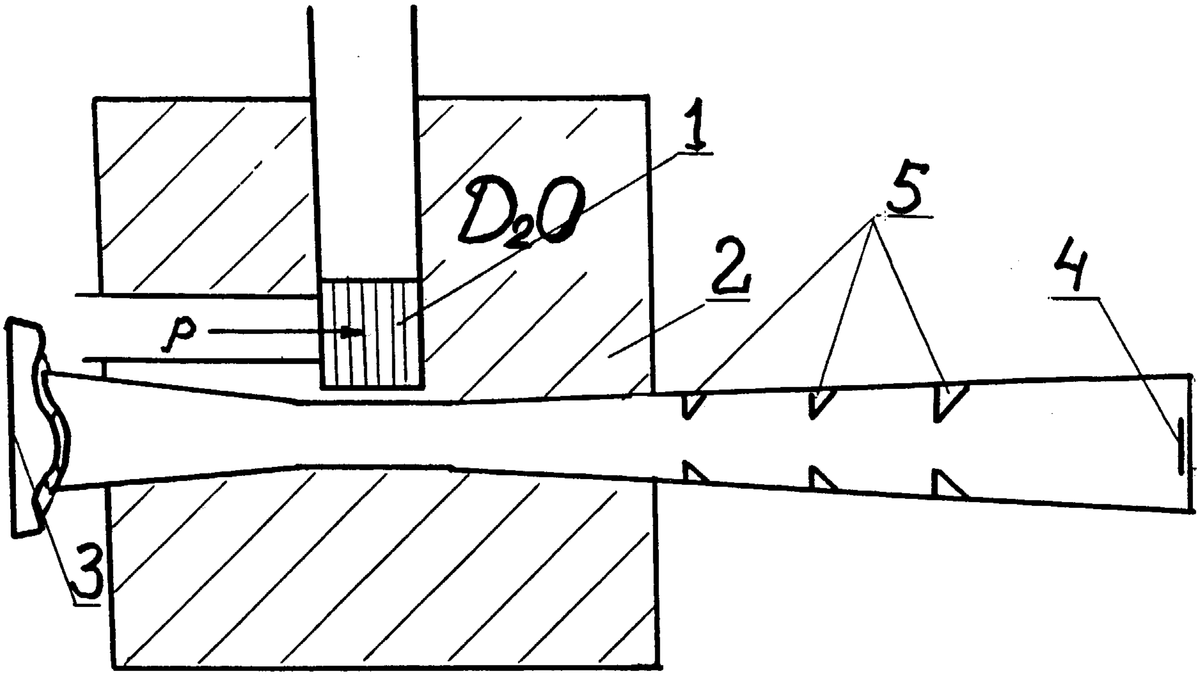
1
D$_2$O
5
2
4
P
3

fig. 2

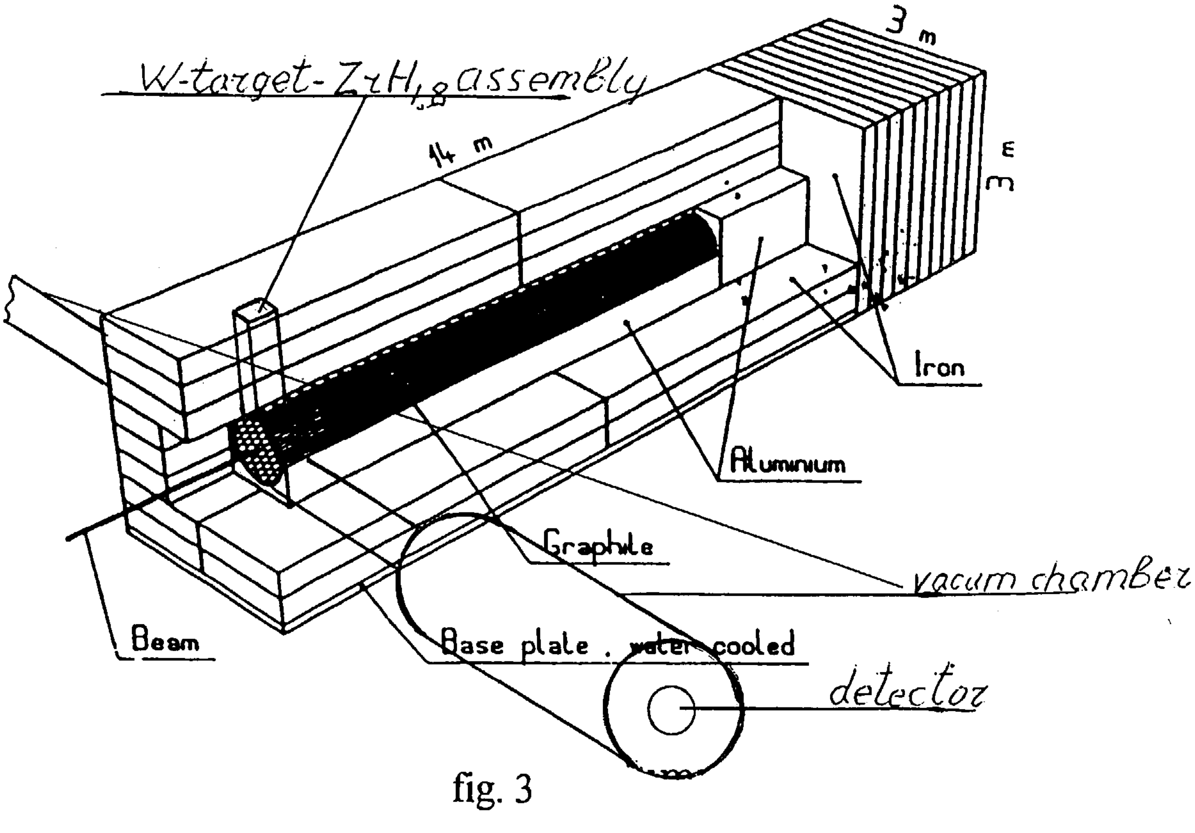
W-target-ZrH$_{1,8}$ assembly
14 m
3 m
3 m
Iron
Aluminium
Graphite
vacum chamber
Beam
Base plate . ~~water~~ cooled
detector

fig. 3