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21.3
Giant Pulses of Slow Neutrons in the LHC Beam Dump

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The possibility for generation the intense slow neutron pulsed fluxes in the modified LHC beam dump is considered. The one-turn extraction of the 7-Tev protons, stored in main ring LHC on the heavy or middle weight target with inner moderator give the possibility to produce the giant slow neutron pulses with relative small duration. For the W-target with inner ZrH_2 moderator the calculations gives the peak flux thermal neutrons density $\sim 1.5 . 10^{19}$ neutr/cm^{2}s with $\sim$ 120 mcs duration.

The possibilities to use such pulses in the neutron physics research is discussed.

1. Introduction

The creation of the unique accelerator-storage complex LHC (fig 1, [6]) opens the unexpected possibilities for physical research in the superhigh dense pulsed fluxes of low-energy neutrons (thermal, cold and ultracold). Here is considered the use of thermal neutrons. The possible experiments with cold and ultracold neutrons in the stage of estimations now.

One of the wonders of nature is that, the circulation time of protons in big cycled accelerators is close to the lifetime of thermal neutrons in the hydrogenous moderators (H_2O, ZrH_2 and others). It is a base to produce the relative short thermal neutron pulses with giant peak flux density (up to $\sim 10^{19}$ - 10^{20} neutr/cm^{2}s).

Yet Robert Wilson [1] proposed to use the high energy proton accelerators (for tens and hundreds GeV) for "electronuclear breeding" (ENB). But here was a mistake - the most effective proton energy for ENB is about 1,2 GeV [2]. With the increase proton energy the direct proton ionization losses decrease and most proton energy loss go for the nuclear interactions, that ends by the neutron production - the main process for ENB. In region $\sim 0,5$ GeV begin the intensive production of the π^0 - mesons. This leads to the secondary ionization losses - through electron-photon showers caused by the π^0-s decay. As a consequence - the broad maximum in the specific yield of neutrons (number of neutrons per the I GeV proton energy) in the proton energy region near 1,2 GeV [2]. The specific spallation neutrons yield for lead at this maximum is about 24 neutr/proton GeV.

The high number protons, stored at the end of the acceleration cycle in rings of big accelerators and his high energy give the possibilities, by using one-turn extraction, to produce a giant neutron pulses [3]. Although the specified neutron yield is relative low, for example only ~ 2,5 neutr/proton GeV at 7 TeV [4], full yield ~ 18000 neutrons per incident proton for 60 cm thick W-target. Main limitations - the heating of target during the pulse.

2.Giant neutron pulses in the beam dump of the LHC.

According to the available information [6] the main LHC mode provides the acceleration and storage of ~ 3.10^{14} protons with energy 7 TeV and "cleaning" the main rings every 10 hours at the end of a physical run,. when the beam has swelled, luminosity degraded and a refill is necessary. 10 hours is the lifetime of luminosity. For the "cleaning" carry out the one-turn extraction and the protons transported into graphite beam dump.

The LHC beam dump is ~ 10 meter long graphite block, surrounded with aluminum and iron layers for shielding (fig. 2). Must be use two beam dumps, for the both main rings.

By [6] the beam damping system (fig. 3) kick horizontally the circulating beam into an iron septum which bends the beam vertically so that it be transported to an external zone sufficiently far away (~ 750 m). For both beam dumps used one extracting system IP6.

For decreasing of the heat load, on the graphite block face is forming the broad beam with help of two orthogonal-deflecting kicker-magnet, which sweep the beam over the front face of the dump. This kickers supply - 14 kHz, 15 kV.

As it can see, by correspondingly synchronization both deflecting magnets, inside of the graphite block arise the ring-shaped beam. If we insert in this beam the thick ring-shaped tungsten target we receive the ring-shaped spallation neutrons source for the generating slow neutrons flux in the inner moderator. The longitudinal distribution of the spallation neutrons sources in such target we can see on fig. 4.

The calculations of V.G.Miroshnichenko based on spallation neutron yield for the thick tungsten target (60 cm, [4]) and the NeuMc code give the thermal neutrons peak flux in ZRH_2 moderator ~ $1.5.10^{19}$ neutr/cm^{2}s. This is possible by use only one third of the full intensity (~10^{14} proton per extraction case). The limitation is connected with the heating of target material. 10^{14} protons give the heating of tungsten in end proton pulse near 2500C. Such heating per pulse seems acceptable if the dense packing of the tungsten roads will be used in the target design (fig. 5). Other protons can be passed through the graphite outside the tungsten. It is possible to use the proton multiple scattering in front of graphite layers for beam swelling in target, if it will be necessary.

The calculations of the thermal neutron pulse duration with the help of NeuMc-code (for 80 mcs revolution time in main ring) gives ~ 120 mcs.

It is possible some optimization of the target for decreasing the delayed neutrons relative yield. The delayed neutrons emission is connected with the nuclear fission. The heavy nucleus fission probability is proportional to Z^2/A. If suppose that such dependence will be for a middle nucleus too, significant decrease in the delayed

neutrons yield will be for Zr-target. The full spallation neutrons yield will be ~ two times smaller. The thermal neutron flux decrease will be not so strong, because of the decreasing flux depression in the moderator caused by neutron capture in target. The target heating will be decrease too.

As we can see from the considered example, the main facilities for the production of the giant neutron pulses are foresee, at least in principle, in the LHC Conceptual Design. This give a possibility and the relative cheapness of this neutron source realization.

For the neutron experiments my be used all intensity of LHC, without any harm interference with the classical particle program.

3. The possible use of the LHC beam dump for the neutron research.

This neutron source give, my be, the first possibility for the direct high accuracy measurement of the neutron-neutron scattering length [5,7].

The neutron-proton scattering cross-section is measured with the accuracy ~ 0,5 %. The possibility for the synonymous interpretation of p-p scattering experiments is limited by the strong coulomb effects. The n-n scattering length has the evaluation only from indirect experiments (f.e. from the n(D,p)2n reaction research). The n-n scattering date is very significant for the fundamental hypothesis of the charge independence of the nuclear forces. Therefore the research programs all new neutron sources contain such experiments (see f.e. [8]). But the relative small intensity and the worse background conditions give not the possibility for the direct n-n experiment.

The calculations of S.A.Novoselov for the beam dump LHC with W-target and ZrH_2 - moderator show (INR, [5,7]), that the neutron current from the vacuum cavity in the moderator through the neutron detector, caused by the n,n scattering in neutron gas, would be ~ 10^5 neutrons per giant pulse. At the one pulse may be received necessary statistical accuracy for the n-n scattering length. More 2 - 3 pulses will allow to research the secondary effects (neutron scattering on recoil nucleus from the vacuum chamber walls, on the reminding gas, the measurements of the slow neutrons energy spectrum by time-of-flight methods and so on). All this gives the hope for high accuracy for the measurements this fundamental value (in range 1 %).

The high thermal neutrons peak densities and the high interaction cross sections for the thermal neutrons will allow the research of the new class multineutron nuclear reactions, when the nuclei captured a few, minimum two neutrons before decay. Up to day such reactions are observe only by the nuclear explosions, but it give not any possibilities their mechanism to investigate. Particularly, appear the possibility for the neutron-surplus transuraniums synthesis by the multineutron capture in heavy targets (f.e. ^{254}Cf, ^{257}Fm', ^{260}Md). In consequence of increasing the life time with neutron number in nucleus, the neutronsurplus isotopes can be relative long-living. This will give the possibilities for detailed investigations of their properties.

It appears the possibility for investigations neutron interaction with radioactive nucleus too, including with the originated by radiation capture during pulse.

The interesting research region my be connected with the neutron solid state physics. For example - the neutron-photon scattering, particularly - experimental

investigation the predicted amplification this process [9] near phonon resonances in crystals.

The considered heavy target in the beam dump LHC will give the intensive neutrino fluxes too. By time selection will be possible to separate the prompt neutrino connected with the proton beam and the delayed ν from the decay of the neutron-deficit nucleus after spallation.

4. Conclusion

The creation of the middle-heavy target assembly inside the graphite beam stop LHC will be allow to develop a new directions for research in particle, nuclear and solid state physics without any harm interference with the classical particle physics program.

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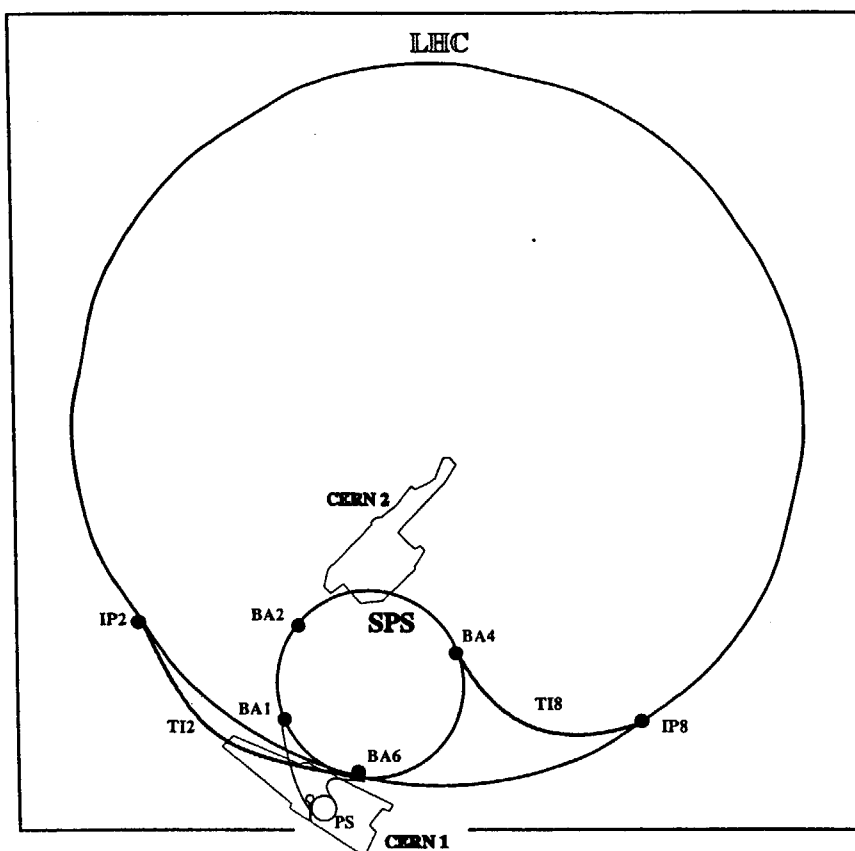
Figure 1: SPS–LHC transfer lines

Energy	E	[TeV]	7.0
Dipole field	B	[T]	8.4
Luminosity	L	[cm^{-2} 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
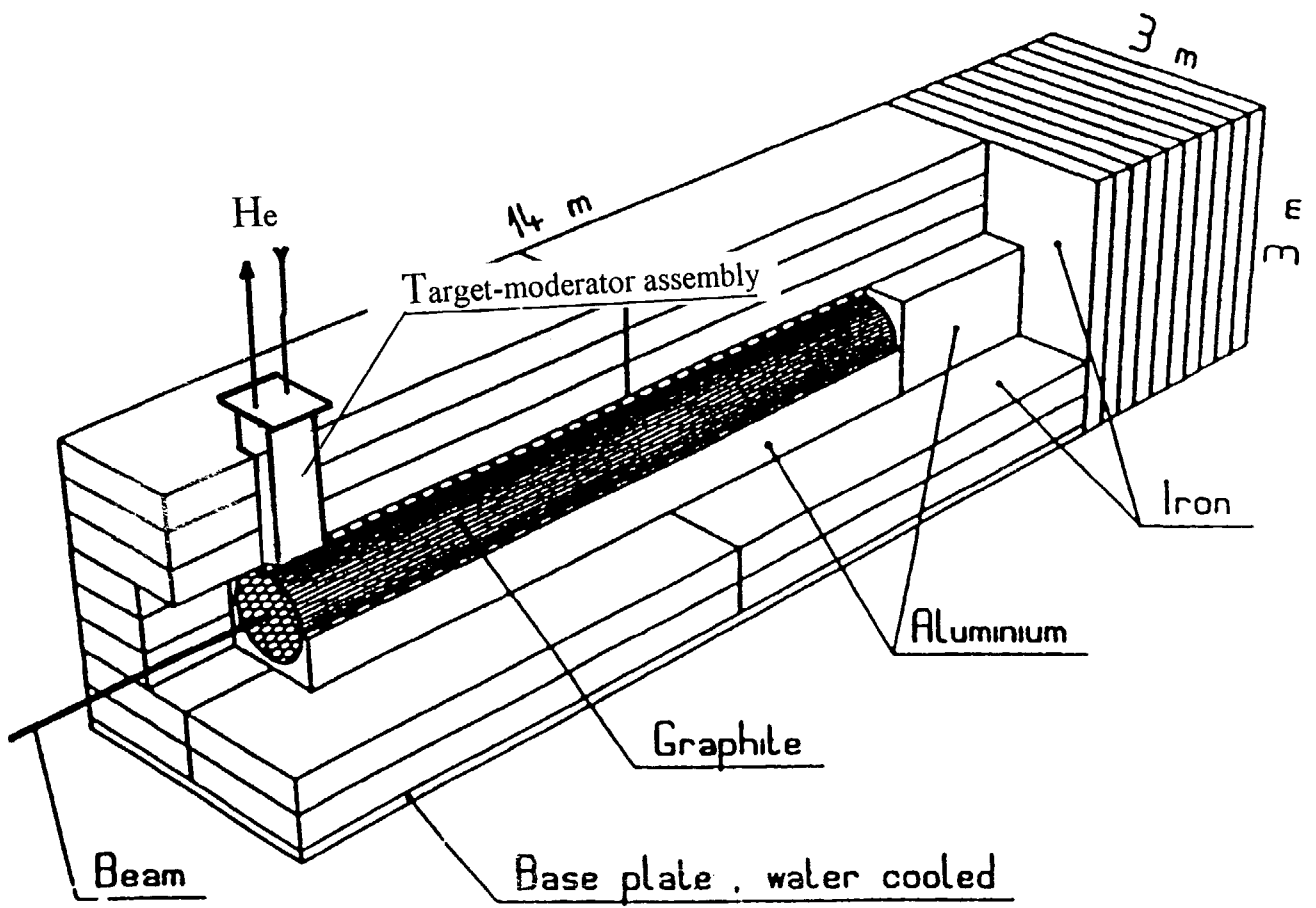
fig. 2
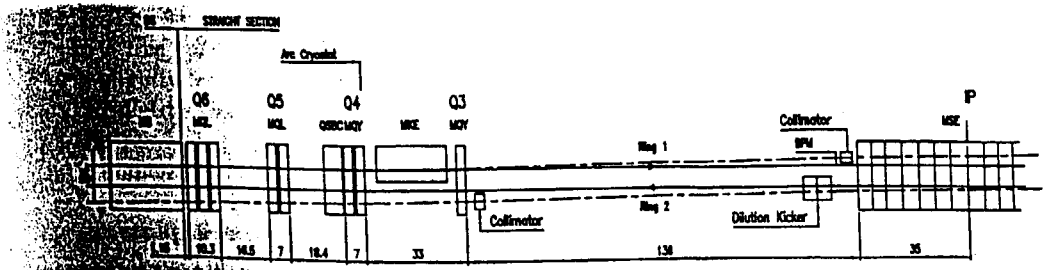
	Units	Septum magnet	Kicker magnet	Diluter horiz.	Diluter vert.
Bending strength	[Tm]	60	7.1	7.0	7.0
Nominal field	[T]	1.0	0.51	1.2	1.2
Overall length	[m]	70	25	8	10
Gap/Beam aperture (horiz. × vert.)	[mm]	45	58 × 58	58 × 42	58 × 42
Rise time	[μs]	d.c.	3		
Frequency	[kHz]			14	14
Flat top	[μs]		90		
Voltage	[kV]		30	15	15
Number of modules		12	14	4	5

fig. 3   Layout of the beam dump insertion at IP6

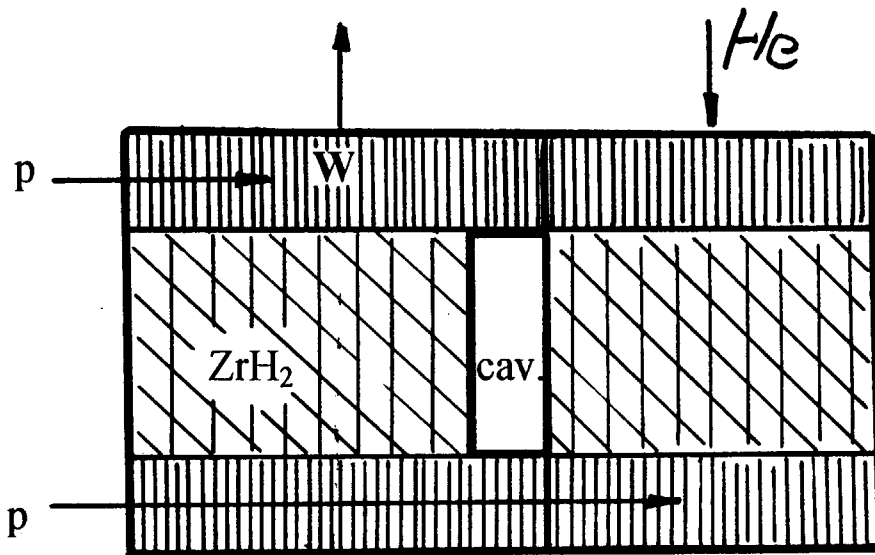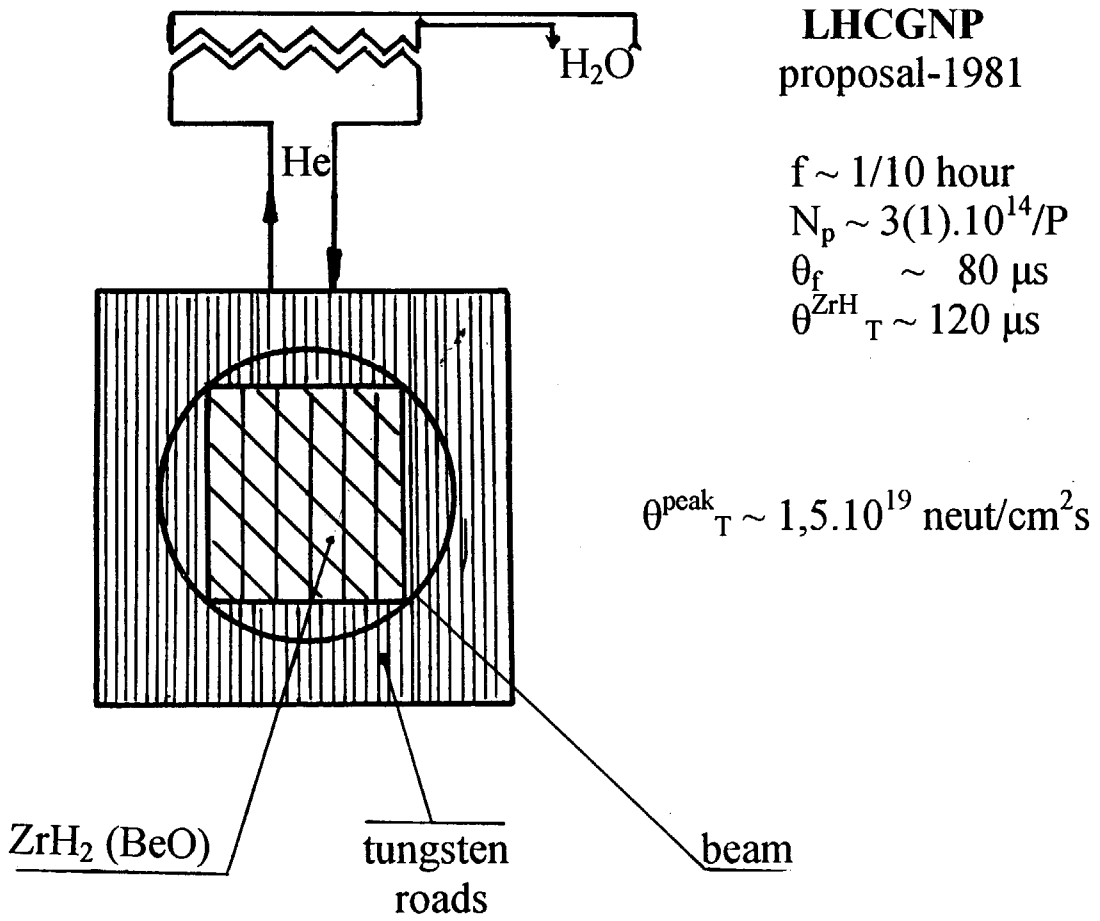Main parameters of the extraction septum, kicker and diluter magnets

fig. 4

LHCGNP
proposal-1981

$f \sim 1/10$ hour
$N_p \sim 3(1).10^{14}/P$
$\theta_f \quad \sim \quad 80 \ \mu s$
$\theta^{ZrH}_T \sim 120 \ \mu s$

$\theta^{peak}_T \sim 1,5.10^{19}$ neut/cm^{2}s

H$_2$O

He

ZrH$_2$ (BeO)

tungsten
roads

beam

p

W

He

p

ZrH$_2$

cav.

fig.5