EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
ORGANISATION EUROPEENNE POUR LA RECHERCHE NUCLEAIRE

CERN - PS DIVISION

PS/ CA/ Note 99-19

PROTONS AVAILABILITY FOR I216 AND FOR THE OTHER PROTONS USERS OF THE PS COMPLEX

J.P. Riunaud

Geneva, Switzerland
25 August 1999

PS/CA Note 99-19

Protons availability for I216 and for the other protons users of the PS Complex

J.P. Riunaud

1. Introduction

A Letter of Intent [1] has been submitted to the SPSC for a search for $\nu_\mu - \nu_e$ oscillations in the TT7 transfer channel, from a target hit by a high intensity/high energy proton beam extracted from the PS. Such an experiment requires, over several years, a significant amount of protons from the PS Complex. This note presents an investigation about the compatibility of these proton requirements with respect to those from the other proton users of the PS Complex for the next few years.

This evaluation takes into account the PS capabilities in terms of maximum accelerated intensity and acceptable rate of losses, the planned additional PS proton users in the years to come and the foreseen accelerator schedules up to 2004 matching CERN energy budget [2].

Possible operational schemes and options optimising the use of the PS Complex proton production capabilities are also presented.

2. PS capabilities

The PS has a cycle time multiple of 1.2 s, the basic period of the whole PS Complex. The maximum proton beam momentum achievable within a 1.2s cycle is 20 GeV/c, and for longer cycles the beam momentum is then limited to 26 GeV/c by the maximum magnetic field of the PS main magnet.

The number of protons delivered to the users over one year basically depends on the maximum number of protons the PS can accelerate in one cycle, on the average rate of beam losses tolerated in the accelerator, and finally on the PS running time and availability.

The present record intensity accelerated in the PS, mainly limited by transverse space charge effects at low energy, is 3.115×10^{13} protons/pulse. As a result of the now complete PSB to PS transfer energy upgrading from 1 to 1.4 GeV one can expect an operational maximum intensity of about 3×10^{13} p^{+}/pulse.

The maximum accepted rate of losses in the PS, defined in the days of the highly proton demanding antiproduction production operation, is 2.4×10^{12} p^{+}/2.4 s cycle, with a maximum of one 2.4 antiproton production cycle per 4.8 s. That is an average rate of losses of 5×10^{11} p^{+}/s. This loss rate leads to a radiation level of the accelerator not too much restrictive for access during shut-down work and to limited equipment damage. Assuming these losses amount to about 5% of the accelerated intensity, the maximum rate of accelerated intensity is then 10^{13} p^+/s.

Over 5600 h of operation in one year, equipment breakdowns and services unavailibility lead to a PS average fault rate of about 8%. Moreover, as the PS does not permanently run at its top performance, statistics show that over a long run at high intensity, the average delivered number of protons to a high intensity user is about 80% of the maximum accelerated intensity.

These figures on the PS capabilities are summarised in table 1.

Maximum p^+ beam momentum (1.2 s cycle)	20 GeV/c
Maximum p^+ beam momentum (2.4 s cycle)	26 GeV/c
Maximum accelerated intensity	3 10^{13} p^+/cycle
Tolerated maximum loss rate	5 10^{11} p^+/s
Max rate of accelerated beam (limited by losses)	10^{13} p^+/s
Average availability	92 %
Overall efficiency (with respect to top performance)	80 %

Table 1. A few PS figures relevant to PS proton users

3. PS Complex proton users

The potential PS proton users which could be in operation in the coming years are listed in table 2, together with a possible beam of 3 x 3 10^{13} p^+/ 14.4 s at 20 GeV/c for I216. In addition to the presently running SPS and East Area beams, the antiproton and neutron production beams, respectively for the Antiproton Decelerator (AD) and for the neutron Time of Flight (TOF) facility are also listed.

PS Complex Proton Users	Nb of p+ required per 14.4 s supercycle	Fraction of PS Supercycle	Operation time over the year
SPS Fixed Target Pysics	2 x $\leq$1.5 10^{13}	2/12	85 - 100 %
Neutrinos in TT7 (I216)	3 x 3 10^{13}	3/12	100 %
Antiproton Decelerator	1.5 10^{13}	2/12	13.5 - 54 %
East Experimental Area	2 - 1 x 0.03 10^{13}	4 - 2/12	84 %
Neutron TOF Facility	0.7 10^{13}	1/12	50 %
Isolde	n x 3 10^{13} from PSB	spare PSB cycles	
Machine Developments and Tests (PSB/PS/AD/SPS)	0 - 3 10^{13}	1 - 4/12	10 - 20 %

Table 2. PS Complex proton users in the coming years. The operation time is given with respect to the total PS running time for physics.

The TOF facility, recently approved as experiment PS213 and to be started-up in early 2000, will require a beam of about 0.7 10^{13} p^+ at 20 GeV/c delivered on a 1.2 s cycle, only for a fraction (about 50 %) of the PS running time.

The AD will be commissionned before the end of 1999. It will require a beam of 1.5 10^{13} p^+ at 26 GeV/c and will only be running for 3000 h/year, that is about 54 % of the PS running time. Moreover, when it is running, its deceleration cycle is at least 60 s long, that is more than 4 PS 14.4 s supercycles. Consequently an AD antiproton production cycle does not need to be permanently produced when AD is running but may at the minimum be present in the PS supercycle only once every 4 PS supercycles, making use of the PS dynamic programme change flexibility. Therefore, on an average the AD antiproton production cycle may be required between 13.5 % and 54 % of the PS running time.

PSB "spare" cycles are used to provide beam to Isolde and/or for PSB Machine Developments. PS "spare" cycles are also used for PS, AD and SPS Machine Developments and tests.

4. PS running time

Accelerator schedules for the next years have been established [2] taking into account the technically feasible accelerator operation and the foreseen energy budget; the latter being the limiting factor. The PS/SPS running periods mentionned in [2] and the non-continuous related physics programme are summarised in table 3. The possible I216 runs are also indicated.

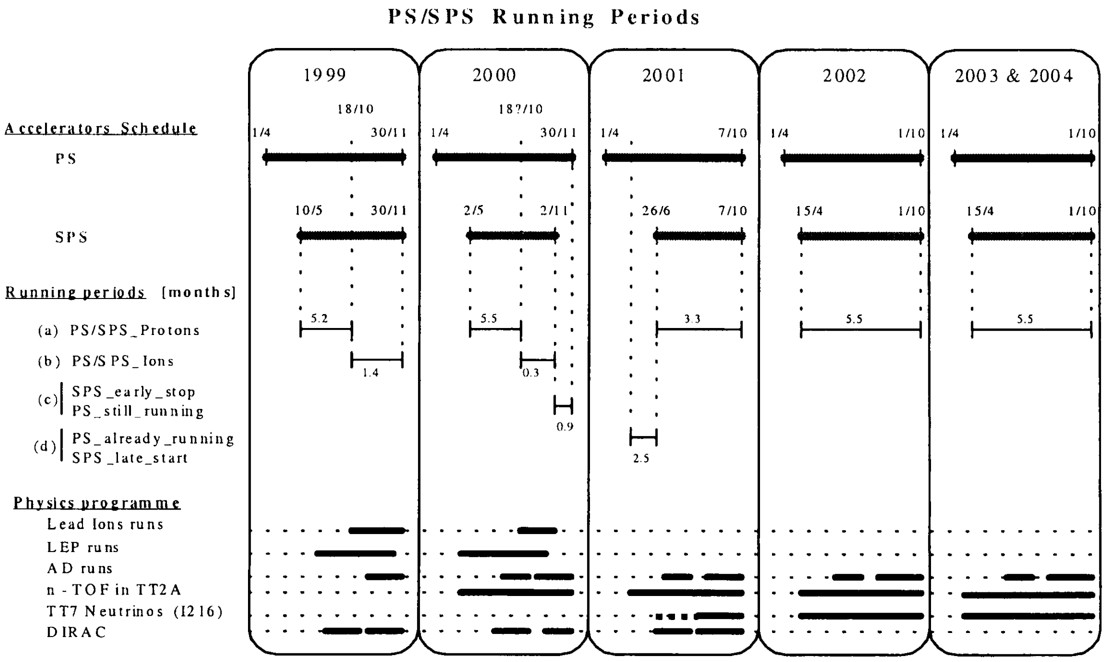


Table 3. PS and SPS running periods and related physics programme, matching the energy budget in the years to come, as defined in ref. 2. The continuous physics programmes (SPS fixed target, Isolde, East Area North & South targets) are not indicated.

After LEP stop in 2001, at the end of the year, when SPS, the East Area and AD are shut-down, running the PS Complex for Isolde and the I216 neutrino experiment in TT7 can provide extra beam to these 2 facilities at a moderate cost. The additional power consumption of 6.5 MW required by Linac/PSB/PS, Isolde and TT2/TT7 would lead to an extra energy cost of 50 KSF/week in october [3]. These extended PS running periods are shown in table 4.

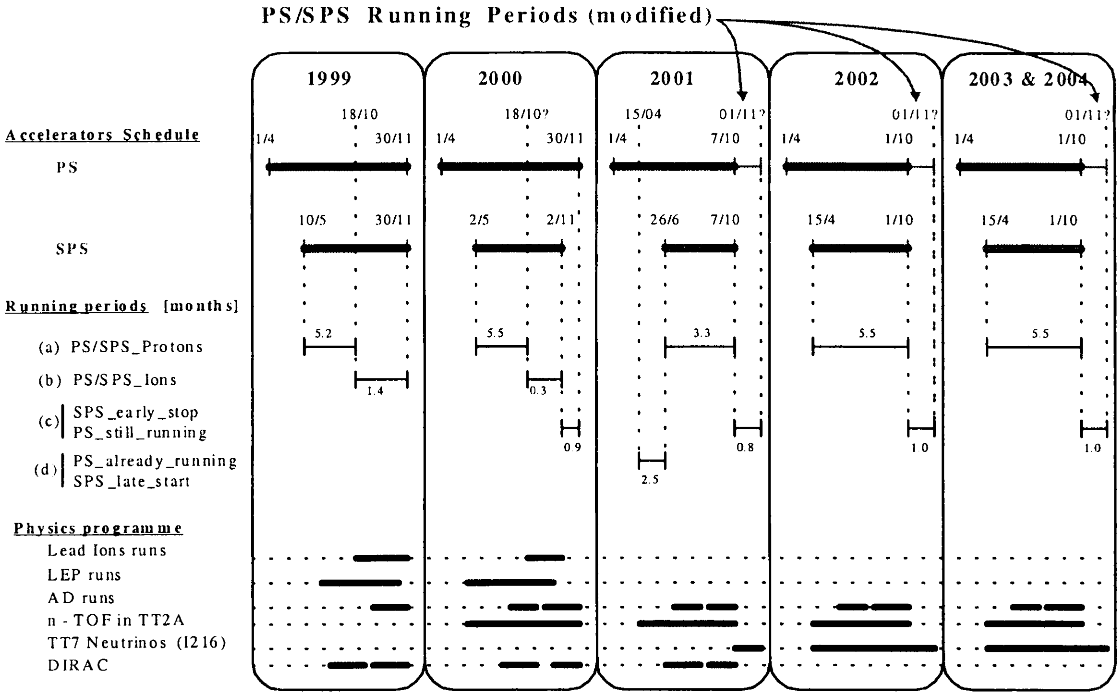
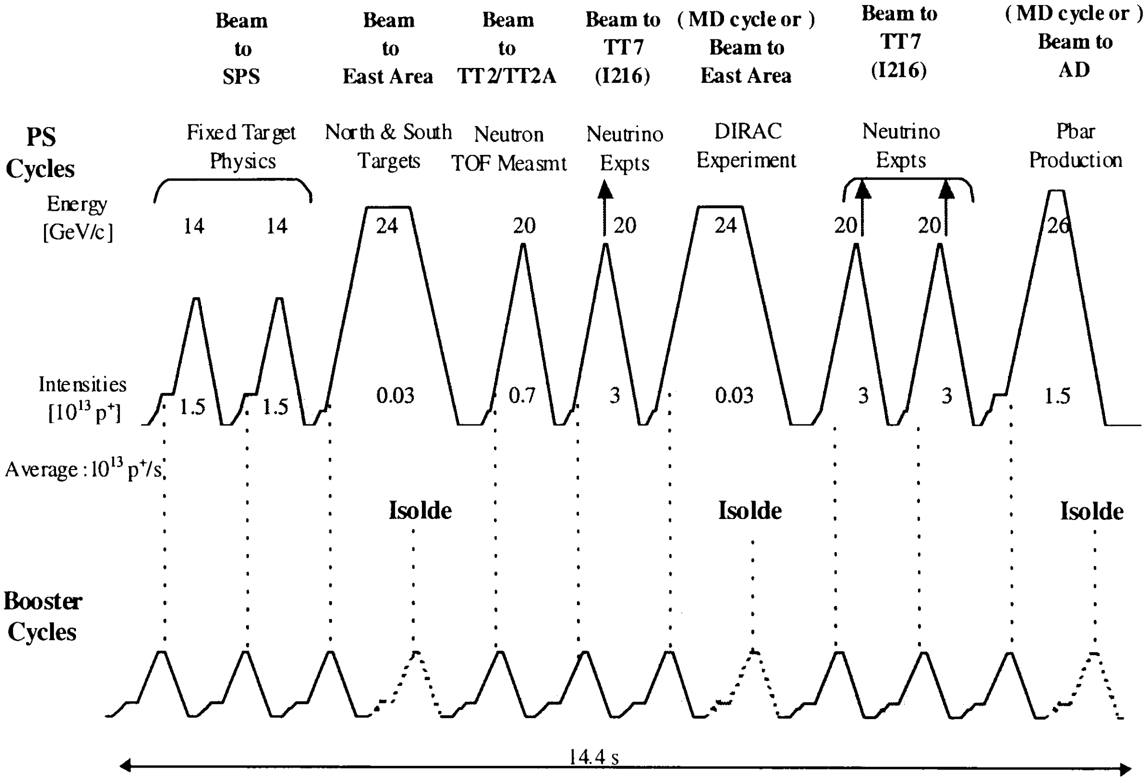


Table 4. PS and SPS running periods and related physics programme, without the early autumn PS shut down proposed in ref. 2.

5. Protons for I216

Taking into account the PS capabilities mentioned in section 2, and all potential users to be fed simultaneously with protons in the next few years, a baseline 14.4 s PS supercycle with up to three 20 GeV/c PS cycles for neutrino production can be set-up. This supercycle, covering the worst case of all users running simultaneously, is presented in fig 1.

One can note that with such a supercycle providing beam to AD and 2 spills to the East Area, the number of PSB pulses available for Isolde is limited to 3 (instead of the usual average of 6) and there is no spare cycle for Machine Development, neither for SPS nor for PS or PSB. However such a supercycle will only be required during the limited AD running time (monday to friday, 27 weeks/year and once per minute) and also during the East Area running time (28 weeks out of the 34 weeks of PS runs). Moreover when the DIRAC experiment has stopped (at the end of 2001) only one cycle will be necessary for the East Area test beams.



cycles for Neutrinos in TT7:	3	cycle(s) for East Area:	2	or 2, 2, 1, 1, 1, 1, 1
cycles for SPS Fixed Target Physics :	2	cycle for AD:	1	or 0, 0, 1, 1, 0, 0, 0
cycle for Neutron TOF Facility:	1	cycle(s) for MD:	0	or 1, 0, 1, 0, 2, 1, 0
		pulses for Isolde:	3	or 3, 4, 3, 4, 3, 4, 5

(other possible cases: the values after "or")

Fig. 1 : PS supercycle with three 20 GeV/c beam for neutrinos in TT7 (I216). The number of pulses for Isolde (3 to 5) and of possible Machine Development cycles (0 to 2) depends on the number of cycles required for the East Area and whether or not AD is running.

During the winter extension of the PS running, I216 and Isolde can be the only PSB/PS users, and the number of PSB pulses for Isolde can be increased up to the maximum of 9, in order to compensate for the lower number of pulses available when the other users are running. An example of supercycle dedicated to I216 and Isolde only is shown in Annex 1. Characteristics of various other 14.4 s PS supercycles, covering the period 2001 - 2004, when I216 could be running, are given in Annex 2.

With supercycle of fig.1, the expected amount of protons delivered per day on the neutrino target can be estimated to be:

$3\ 10^{13}$	x	3	x	(3600/14.4)x 24	x	.92	x	.80	=	**$4\ 10^{17}$ pot/day**
protons per PS cycle		cycles per supercycle		supercycles per day		PS availability		overall efficiency		

From this daily flux, the cumulated pot until end of 2004 can be estimated for the running periods presented in tables 3 and 4 :

- Without extension of the PS running period in winter (as in table 3) :
  2002-2004 (5.5 months/year) $4\ 10^{17}$ x 30 x 5.5 x 3 = **$19.8\ 10^{19}$ pot**
- With extension of the PS running period in winter (as in table 4) :
  2001 (0.8 months) $4\ 10^{17}$ x 30 x .8 = $0.96\ 10^{19}$ pot
  2002-2004 (6.5 months/year) $4\ 10^{17}$ x 30 x 6.5 x 3 = $23.4\ 10^{19}$ pot
  That is a total of **$24.4\ 10^{19}$ pot**

Therefore, with the running times proposed in table 4, the I216 required amount of 2.5 10^{20} pot can be reached from early october 2001 till end of october 2004.

6. Possible options

Most of the PS cycles make use of all the beam from the 4 PSB rings. However, the 2.4s - 24 GeV/c PS cycles providing a beam for slow extraction to the East Area only requires a few 10^{11} p^{+}, easily produced by a single PSB ring. Currently, during the PSB cycle providing beam dedicated to the East Area, the required low intensity beam is accelerated in one PSB ring, while no beam is injected in the other 3.

The PSB is able to accelerate different intensities in each of its 4 rings but cannot presently delivers these beams to different destinations. To overcome this limitation and to make full use of the PSB potential, 2 options can be investigated :

(i) Feed 2 different PS proton users on a single 2.4s cycle for East Area. This could be achieved by accelerating simultaneously in the PSB/PS chain a beam made up of bunches coming from several PSB rings, very different intensities : 1 to 3 PSB rings at high intensity (max 0.7 10^{13} p^{+} /ring) and 1 PSB ring with 3 10^{11} p^{+}. The former - high intensity beam -, could be fast extracted at 20 GeV/c from the PS either to the neutrino target in TT7 (3 rings totalling 2.1 10^{13} p^{+}) for I216, or to the neutron target in TT2A (1 ring of 0.7 10^{13} p^{+}) for the TOF facility. The latter - low intensity beam -, could be slow extracted at 24 GeV/c to the East Area.

(ii) Share the beam from a single PSB cycle between PS and Isolde with the help of deflecting elements to be designed, constructed and installed in the PSB to PS transfer channel.

The first option does not require any additional hardware but needs beam study time as several beam dynamics issues have to be addressed to make sure such schemes can be operational : simultaneous acceleration of high and low intensity bunches, bunch compression for TOF beam followed by bunch expansion before slow extraction, etc ... This option would allow provision for an appreciable amount of extra protons to either TOF or I216, "in the shadow" of the East Area 2.4 s cycle. It is currently being investigated and initial tests indicate that it looks promising and could be operational at the low intensity TOF start-up in 2000. An example of a possible supercycle making use of this option is shown in Annex 1.

The second option requires additional new hardware : a horizontal kicker and a double septum. A lay-out of the PSB to PS transfer line with these new devices is sketched in fig 3. More details of this scheme, namely bunches deflections for Isolde and PS, are shown in Annex 3. This option, requiring precise studies and equipment design, is under investigations.

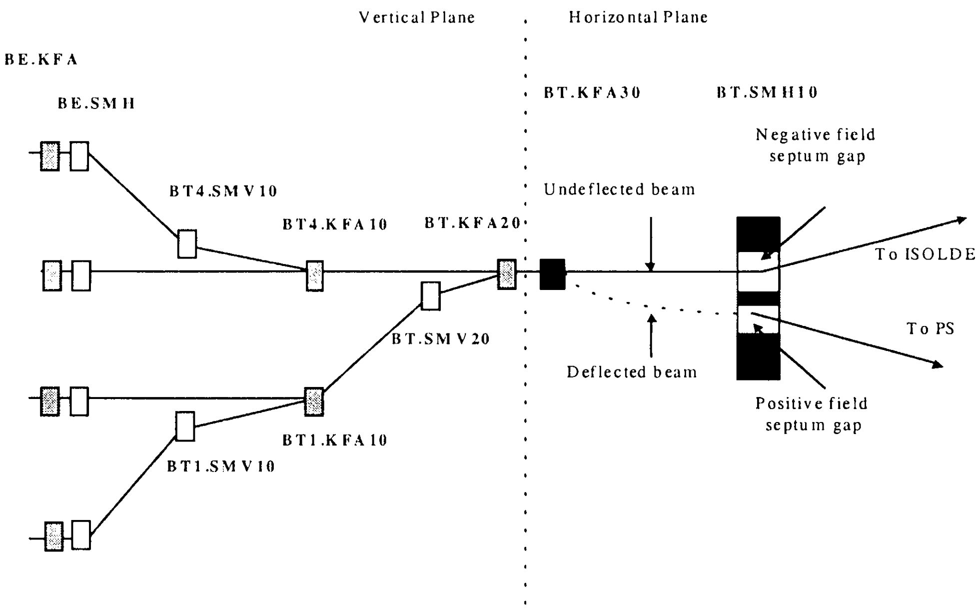


Fig 3. Kicker and Septa in the PSB/PS transfer line, with new kicker (BT.KFA30) and septum (BT.SMH10), to be designed and constructed, for Isolde/PS beam sharing

7. Conclusions

The amount of protons on target required by I216 and the other users of the PS protons can match the expected number of protons/year which will be delivered by the PS in the years to come, provided a few actions are taken :

- Do not shut the PS down in the autumn period, as early as it is foreseen for the SPS to reduce electricity costs, but keep it running in october for Isolde and I216 only.
- Maintain a careful management of high intensity beam losses in the PS to keep the radiation level in the machine to an acceptable level.
- Make full use of the PS dynamic programme change flexibility to profit from spare cycles unrequested by non permanent users like AD.
- Establish adequate scheduling of the various operations to match the users running times with the protons availability (i.e. large number of pulses for Isolde in autumn, Machine Developments when East Area and AD are not running, etc ...)

Moreover, parallel operation of the PS East Area with either TOF or I216, which is currently being tested and looks promising, could add some more flexibility to the present PSB/PS proton sharing between all users.

Finally, an additional hardware implementation in the PSB to PS transfer line, to share a single PSB cycle beween PS and Isolde, could also help in allowing the proton users to take full advantage of all the beam that can be produced by the PSB.

Acknowledgments

The author wishes to thank J. Boillot, R. Cappi and D.J. Simon for their appreciable comments on the manuscript.

References

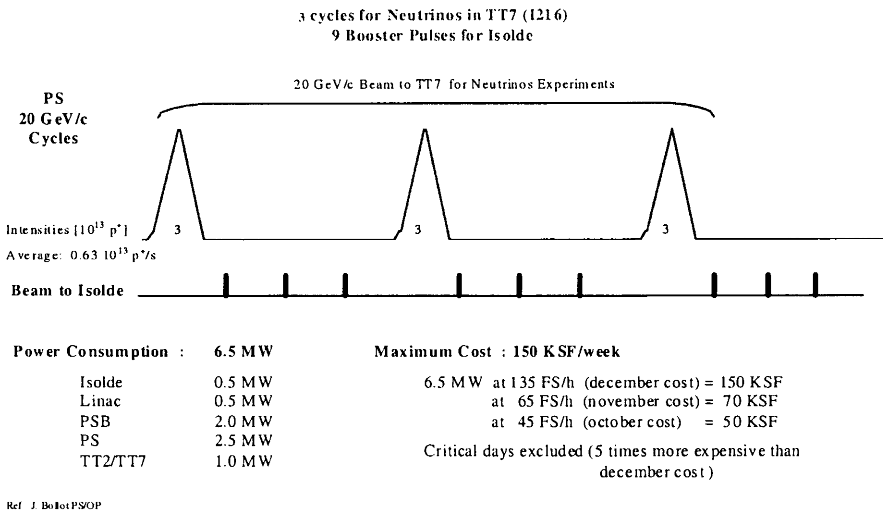
[1] I216 Letter of Intent, CERN-SPSC/97-21, SPSC/I216, October 10, 1997 : Search for $\nu_{\mu} - \nu_{e}$ oscillation at the CERN PS

[2] AC Note (98-01), June 11, 1998 : CERN Energy Budget and Accelerator Schedules

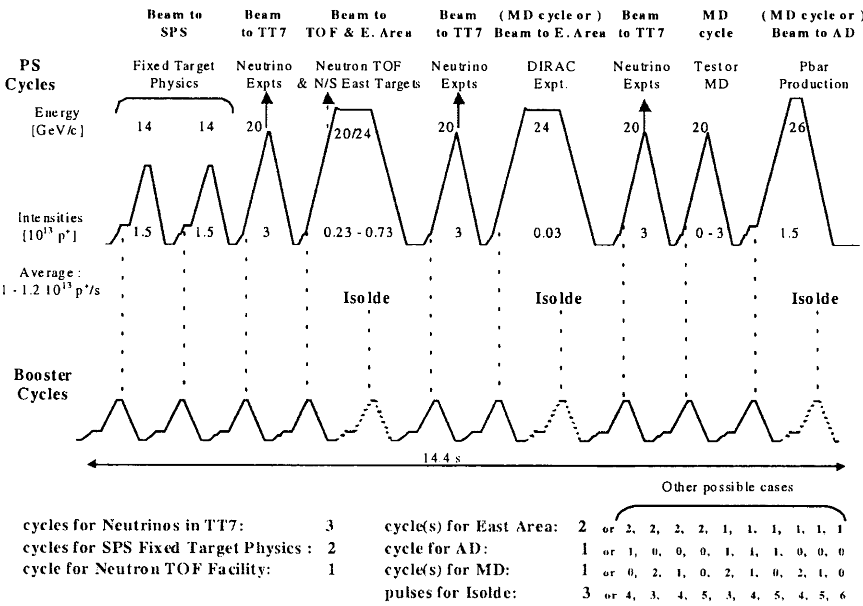
[3] J. Boillot PS/OP private communication

Annex 1

PS Supercycles



PS 14.4 s supercycle, dedicated to Neutrinos (I216) and Isolde only, that could be used during the october PS running period 2001-2004. As the rate of accelerated intensity is lower than 10^{13} p^{+}/s , an additional 4th cycle for I216 can be inserted, but at the expense of one pulse less for Isolde.



PS 14.4 s supercycle with common cycle for neutron TOF and East Area.
The number of pulses for Isolde (3 to 6) and of Machine Development cycles (0 to 2) depends on the number of cycles for the East Area cycle and whether or not AD is running. With this supercycle, the rate of accelerated intensity may become higher than the usual 10^{13} p^{+}/s.

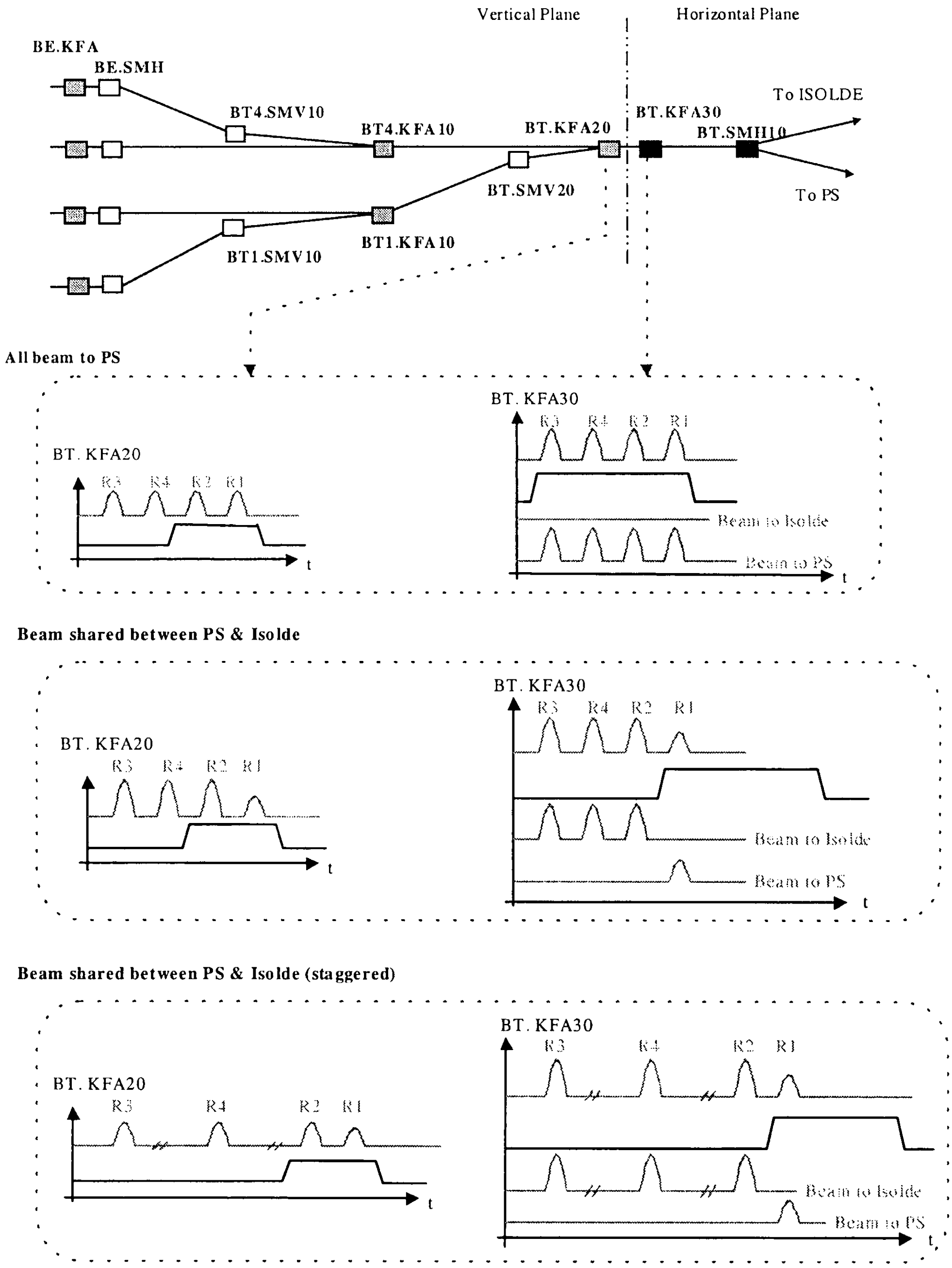
Annex 2 - Possible uses of PSB/PS Beam in 2001 - 2004

YEAR	Period	Super cycle Id.	SFT F. Target 1.2 s	Neutrinos in TT7 1.2 s	n-TOF in TT2A 1.2 s	East Area N/S Targets 2.4 s	East Area DIRAC 2.4 s	AD Pbar Prod. 2.4 s	SPS/MD LHC Tests 2.4 s	PS/MD AD Tests 1.2 s	PS/MD LHC Tests 2.4 s	ISOLDE Nb of Pulses	PS average Intensity [10^{13} p/s]
2001	(d)	# 1	no	3 x 5 [0]	0.7 x 1 [0]	.03 x 1 [1]	.03 x 1 [1]	1.5 x 1 [1]	no	no	no	3	1.20
		# 2	no	3 x 3 [0]	0.7 x 3 [0]	.03 x 1 [1]	.03 x 1 [1]	1.5 x 1 [1]	no	no	no	3	0.88
		# 3	no	3 x 3 [0]	0.7 x 1 [0]	.03 x 1 [1]	.03 x 1 [1]	1.5 x 1 [1]	no	no	flat cycle [2]	5	0.78
		# 4	no	3 x 5 [0]	0.7 x 1 [0]	.03 x 1 [1]	.03 x 1 [1]	no	1.5 x 1 [1]	no	no	3	1.20
		# 5	no	3 x 3 [0]	0.7 x 3 [0]	.03 x 1 [1]	.03 x 1 [1]	no	1.5 x 1 [1]	no	no	3	0.88
		# 6	no	3 x 3 [0]	0.7 x 1 [0]	.03 x 1 [1]	.03 x 1 [1]	no	1.5 x 1 [1]	no	flat cycle [2]	5	0.78
		# 7	no	3 x 5 [0]	0.7 x 1 [0]	.03 x 1 [1]	.03 x 1 [1]	no	no	no	1.5 x 1 [1]	3	1.20
		# 8	no	3 x 3 [0]	0.7 x 3 [0]	.03 x 1 [1]	.03 x 1 [1]	no	no	no	1.5 x 1 [1]	3	0.88
		# 9	no	3 x 3 [0]	0.7 x 1 [0]	.03 x 1 [1]	.03 x 1 [1]	no	flat cycle [2]	no	1.5 x 1 [1]	5	0.78
		# 10	no	3 x 3 [0]	0.7 x 1 [0]	.03 x 1 [1]	.03 x 1 [1]	no	flat cycle [2]	no	flat cycle [2]	6	0.68
		# 11	no	3 x 5 [0]	0.7 x 3 [0]	.03 x 1 [1]	.03 x 1 [1]	no	no	no	no	2	1.20
		# 12	no	3 x 3 [0]	0.7 x 1 [0]	.03 x 1 [1]	.03 x 1 [1]	no	no	0.02 x 1 [0]	0.7 x 2 [1]	3	0.78
	(a)	# 1	1.5 x 2 [0]	3 x 3 [0]	0.7 x 1 [0]	.03 x 1 [1]	.03 x 1 [1]	1.5 x 1 [1]	no	no	no	3	1.00
		# 2	1.5 x 2 [0]	3 x 3 [0]	0.7 x 1 [0]	.03 x 1 [1]	.03 x 1 [1]	no	1.5 x 1 [1]	no	no	3	1.00
		# 3	1.5 x 2 [0]	3 x 3 [0]	0.7 x 1 [0]	.03 x 1 [1]	.03 x 1 [1]	no	no	no	1.5 x 1 [1]	3	1.00
		# 4	1.5 x 2 [0]	3 x 3 [0]	0.7 x 3 [0]	.03 x 1 [1]	.03 x 1 [1]	no	no	no	no	2	1.00
		# 5	1.5 x 2 [0]	3 x 5 [0]	0.7 x 1 [0]	.03 x 1 [1]	.03 x 1 [1]	no	no	no	no	2	1.30
		# 6	1.5 x 2 [0]	3 x 3 [0]	0.7 x 1 [0]	.03 x 1 [1]	.03 x 2 [2]	no	no	no	no	3	0.89
	(c)	# 1	no	3 x 3 [0]	no	no	no	no	no	no	no	9	0.63
2002 and after	(a)	# 1	1.5 x 2 [0]	3 x 3 [0]	0.7 x 1 [0]	.03 x 1 [1]	.03 x 1 [1]	1.5 x 1 [1]	no	no	no	3	1.00
		# 2	1.5 x 2 [0]	3 x 3 [0]	0.7 x 1 [0]	.03 x 1 [1]	.03 x 1 [1]	no	1.5 x 1 [1]	no	no	3	1.00
		# 3	1.5 x 2 [0]	3 x 3 [0]	0.7 x 1 [0]	.03 x 1 [1]	.03 x 1 [1]	no	no	no	1.5 x 1 [1]	3	1.00
		# 4	1.5 x 2 [0]	3 x 3 [0]	0.7 x 3 [0]	.03 x 1 [1]	.03 x 1 [1]	no	no	no	no	2	1.00
		# 5	1.5 x 2 [0]	3 x 5 [0]	0.7 x 1 [0]	.03 x 1 [1]	.03 x 1 [1]	no	no	no	no	2	1.30
		# 6	1.5 x 2 [0]	3 x 3 [0]	0.7 x 1 [0]	.03 x 1 [1]	.03 x 2 [2]	no	no	no	no	3	0.89
	(c)	# 1	no	3 x 3 [0]	no	no	no	no	no	no	no	9	0.63

Key : 1.5 x 2 [0] means 1.5 10^{13} particles per cycle x 2 PSB pulses , [0 spare PSB pulses for Isolde]
flat cycle [2] means No beam but time slot allocated in the supercycle, [2 spare PSB pulses for Isolde]
Periods (a), (d) or (c) refer to tables 3 and 4 "PS/SPS Running Periods"

14.4 s supercycles

Annex 3
PSB/PS Transfer Kicker waveforms



Waveforms, with respect to the PSB bunches, of the existing last vertical recombination kicker BT.KFA20 and of the proposed new horizontal kicker BT.KFA30, for operations requiring either all beam to the PS or beam sharing between PS and Isolde. The 2 cases of "normal" and "staggered" extraction for Isolde are represented. When kicker BT.KFA30 is not activated, all the beam goes to Isolde.

Distribution

PS Group Leaders and Associates
R. Cappi
C. Détraz/DG
K. Hubner/DG
K. Konigsmann/EP
P. Loverre/EP
V. Palladino/EP
T. Ruf/EP
R. Santacesaria/EP
E. Tsesmelis/EST