RECOMMENDATIONS OF THE HIP WORKING GROUP*

* http://ab-div.web.cern.ch/ab-div/Projects/hip/

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Introduction: HIP WG Members

M. Benedikt	PSB	Secretary
K. Cornelis	SPS	
R. Garoby		Chairman
E. Metral	PS	
F. Ruggiero	LHC	
M. Vretenar	Linac(s)	

Introduction: Mandate

- Define a list of specifications for beam performance based on perceived future physics needs. } **~ done**
- Investigate possible changes to the CERN complex of proton accelerators. } **done**
- Publish a summary of various alternatives and compare them in terms of performance, flexibility and approximate cost. The associated requirements in technical competence should be underlined. A preferred scheme should be indicated with the possible option of a staged realisation. } **Partly done**
- Present the recommendations for approval by the A&B management by the end of 2003. } **Delayed to March 2004**

Introduction: Work history

- Minutes and presentations available at
  http://ab-div.web.cern.ch/ab-div/Projects/hip/
- Builds upon previous work:
  - CERN/PS 2001-041 (AE), CERN/SL 2001-032, **Increasing the Proton Intensity of PS and SPS**, R. Cappi (editor)
  - LHC Project Report 626, **LHC Luminosity and Energy Upgrade: a Feasibility Study**, F. Ruggiero (ed.)
- 24 meetings since January 9, 2003
- Intermediate reports at ATC (06/03), ISOLDE upgrade SG (09/03) and CNGS TWG (01/04)
- Final report in preparation (~ April 2004)

Introduction: Subjects & speakers

SPEAKERS	USERS' NEEDS	ACCELERATORS' ISSUES
S. Baird, M. Benedikt		Proton beam availability
T. Nilsson	ISOLDE upgrade and future plans	
M. Benedikt, G. Metral		Potential of shorter basic period
K. Elsener	CNGS needs and potential	
M. Giovannozzi		PS new multi-turn ejection
M. Lamont		SPS ppm and fast supercycle changes
M. Vretenar		Possible upgrades of linacs
A. Mueller (CNRS)	EURISOL	
A. Blondel (Geneve)	Future neutrino beams	
H. Schonauer		RCS option
F. Ruggiero		Potential LHC upgrades
D. Manglunki		CT status and possible improvement
E. Shaposhnikova		High intensity in SPS: longitudinal issues
K. Cornelis		High intensity in SPS: transverse issues
J. Virdee	Future LHC upgrades	

Users' requests (1)

- The present priorities of CERN have been used, and only the users communities already working on the site have been considered. Namely, the needs of LHC, neutrino and radio-active ion beam physics have been taken into account. For the other present users (AD, PS East area, nTOF, SPS fixed target) , the assumption has been that their requirements do not significantly influence the choice, and that every scenario envisaged would be compatible.
- In terms of schedule and resources, the requested beams fall into 3 main categories:
  - the short term, "low" (ideally zero) cost demands, which match the present commitments of CERN and belong to the approved physics programme,
  - the medium term, "medium" cost requests, which correspond to modest and progressive increases of performance for the present experiments,
  - the long term, "high" cost wishes, which are linked to major equipment upgrades and to new experiments suggested for integration inside the future physics programme of CERN.

Users' requests (2)

USER	CERN COMMITMENT*	USERS' WISHES	
	Short term	Medium term *[~ asap !]*	Long term *[beyond 2014]*
LHC	Planned beams	Ultimate luminosity	Luminosity upgrades
FT (COMPASS)	0.2×10^{6} spills/y ?	1×10^{6} spills/y	
CNGS	4.5×10^{19} p/year	Upgrade ~ ×2	
ISOLDE	1.92 μA **	Upgrade ~ ×5	
Future ν beams			> 2 GeV / 4 MW
EURISOL			1-2 GeV / 5 MW

* Reference value for analysis

** 1350 pulses/h – 3.2×10^{13} ppp

Main upgrades considered

Description	Beneficiary
“Loss-less” PS multi-turn ejection	CNGS
Double PSB batch for CNGS	CNGS
Reduced basic period (0.9 & 0.6 s)	ISOLDE
Energy upgrade of linac 2	ISOLDE, CNGS
Linac 4 (=> single PSB batch for LHC)	LHC, ISOLDE
Low energy RCS (PSB replacement)	LHC, ν
SPL	LHC, EURISOL, ν
30 GeV RCS	LHC, ν
New 30 GeV PS (~ “PS XXI”)	LHC
1 TeV LHC injector (“Super-SPS”)	LHC

Analysis*: Flux

*** by M. Benedikt & S. Baird**

Basic Assumptions 2007 [2010]:

(no shortage of protons in 2006 because LHC is not running)

- **Accelerators time schedule**
  - PS operating time/year: 5400 h (without setting-up)
  - SPS/LHC operating time: 4700 h (without setting-up)
  - SPS in LHC filling mode: 15 % [5 %] of the time
  - SPS in LHC pilot mode: 35 % [10 %] of the time
- **Availability**
  - PS & PSB: 90 %
  - SPS for CNGS: 80 %
- **Beam intensities**
  - SPS intensity for CNGS: 4.4×10^{13} ppp 7×10^{13} ppp
  - PS intensity for CNGS: 3×10^{13} ppp 4×10^{13} ppp

Analysis: SPS supercycles

"Best" compromise based on basic operational requirements*

1. **LHC filling supercycle**
   1 LHC filling (flat porch for 4 PS injections)
   Nominal length ≥ 21.6 s
2. **LHC pilot supercycle**
   1 LHC pilot + 2 CNGS
   Nominal length: 22.8 s
3. **CNGS & FT supercycle**
   3 CNGS + 1 FT + 1 MD
   Nominal length: 34.8 s

*** Assumes capability of quickly changing the SPS supercycle and the presence of a solid-state switch for powering magnets in TT41**

Analysis: Flux with 1.2 s basic period

Linac 4

	LHC double CNGS single	LHC double CNGS double	LHC single CNGS single	Basic user request
CNGS flux (pot/year)	**$4.4\ 10^{19}$**	**$6.4\ 10^{19}$**	**$7\ 10^{19}$**	$4.5\ 10^{19}$
East Hall spills	**$1.5\ 10^{6}$**	**$1.4\ 10^{6}$**	**$1.5\ 10^{6}$**	$1.3\ 10^{6}$
NTOF flux (pot/year)	**$1.7\ 10^{19}$**	**$1.5\ 10^{19}$**	**$1.7\ 10^{19}$**	$1.5\ 10^{19}$
ISOLDE flux (μA) **[nb. of pulses/hour]**	**1.75** **1230**	**1.32** **930**	**3.7** **1310**	1.9 1350
FT spills	**$1.9\ 10^{5}$**	**$1.8\ 10^{5}$**	**$1.9\ 10^{5}$**	$6\ 10^{5}$
LHC SC length	22.8 s	25.2 s	22.8 s	
CNGS + FT SC length	34.8 s	38.4 s	34.8 s	

Analysis: Flux with 0.9 s basic period

Linac 4

	LHC double CNGS single	LHC double CNGS double	LHC single CNGS single	Basic user request
CNGS flux (pot/year)	$4.3\ 10^{19}$	$6.4\ 10^{19}$	$6.8\ 10^{19}$	$4.5\ 10^{19}$
East Hall spills	$1.5\ 10^{6}$	$1.4\ 10^{6}$	$1.5\ 10^{6}$	$1.3\ 10^{6}$
NTOF flux (pot/year)	$1.6\ 10^{19}$	$1.5\ 10^{19}$	$1.6\ 10^{19}$	$1.5\ 10^{19}$
ISOLDE flux (μA) **[nb. of pulses/hour]**	3.1 2150	2.6 1820	6.4 2240	1.9 1350
FT spills	$1.9\ 10^{5}$	$1.8\ 10^{5}$	$1.9\ 10^{5}$	$6\ 10^{5}$
LHC SC length	23.4 s	25.2 s	23.4 s	
CNGS + FT SC length	35.1 s	37.8 s	35.1 s	

Analysis:
Flux with 0.6 s basic period

Linac 4

	LHC double CNGS single	LHC double CNGS double	LHC single CNGS single	Basic user request
CNGS flux (pot/year)	$4.4\ 10^{19}$	$6.7\ 10^{19}$	$7\ 10^{19}$	$4.5\ 10^{19}$
East Hall spills	$1.5\ 10^{6}$	$1.4\ 10^{6}$	$1.5\ 10^{6}$	$1.3\ 10^{6}$
NTOF flux (pot/year)	$1.7\ 10^{19}$	$1.6\ 10^{19}$	$1.7\ 10^{19}$	$1.5\ 10^{19}$
ISOLDE flux (μA) **(nb. of pulses/hour)**	5.6 3930	5.1 3550	11.4 4010	1.9 1350
FT spills	$1.9\ 10^{5}$	$1.8\ 10^{5}$	$1.9\ 10^{5}$	$6\ 10^{5}$
LHC SC length	22.8 s	24 s	22.8 s	
CNGS + FT SC length	34.8 s	36.6 s	34.8 s	

Analysis: Brightness for LHC

Problem of the present scheme:
Bunch intensities within the same emittances

	1993	2003
LHC nominal	1.05×10^{11}	1.15×10^{11}
LHC ultimate	1.7×10^{11}	1.7×10^{11}
PS nominal (estimate)	1.05×10^{11}	1.3×10^{11}
PS ultimate (estimate)	1.7×10^{11}	2×10^{11}
PS max. (experimental)		1.4×10^{11}

Including transmission loss to SPS @ 450 GeV

Solutions

	PS batch compression	Linac 4	Linac 4 + batch compression
Bunch intensity (PS max.)	2.65×10^{11}	2×10^{11}	3×10^{11}
Nb. of bunches / PS pulse	42 (48)	72	48
PS repetition period	3 BP	2 BP	2 BP

Analysis: Potential of future accelerators

	INTEREST FOR			
	LHC upgrade	**Neutrino physics beyond CNGS**	**Radio-active ion beams (EURISOL)**	**Others**
Low energy 50 Hz RCS (~ 400 MeV / 2.5 GeV)	Valuable	Very interesting for super-beam	No	?
50 Hz SPL (> 2 GeV)	Valuable	Very interesting for super-beam + beta-beam	Ideal	Spare flux $\Rightarrow$ possibility to serve more users
High energy 8 Hz RCS (30 GeV)	Valuable	Very interesting for neutrino factory	No	Valuable
New PS (30 GeV)	Valuable	No	No	Valuable
1 TeV LHC injector	Very interesting for doubling the LHC energy	No	No	Marginal

Analysis: Comments

- Irradiation caused by beam loss at high intensity is a major concern (Report by M. Benedikt).
- 0.6 s basic period is much more expensive than 0.9 s and would severely limit the flexibility of the PSB.
- Increasing the intensity per pulse in the SPS is the only means to increase the flux for CNGS. Many issues need investigation [machine impedance (kickers, RF…), injection energy, need for bunching in the PS…].
- CNGS and FT (COMPASS) share the available SPS cycles. In the analysis, priority has been given to CNGS.

$\Rightarrow$ too few FT spills (factor of ~ 4). Any compensation to FT will be detrimental to CNGS.

Recommendations: Short term & high priority (1)

"…***we strongly support:***

- the on-going efforts to modify the control system for increasing the flexibility in the change of operating modes. ***We underline that, to achieve that goal in 2006, the accelerators' equipment must imperatively be adapted before that date.***

- the decision to install immediately a solid state device to switch to the current between TI8 and TT41 magnets and to have it available for the start-up in 2007."

Recommendations: Short term & high priority (2)

"… we consider of the utmost importance to give a high priority to the minimization of beam loss and irradiation:

- by developing rapidly the proposed new multi-turn ejection scheme from the PS and implementing it as soon as possible,
- by improving the flexibility and ease of control of the machine parameters (independent control of the current in the 5 PFWs circuits in the PS, beam instrumentation and feedbacks,…),
- by practicing with high intensity beams before the shutdown in 2005, to train staff and precisely determine the actual capabilities and weaknesses in the accelerators' complex,
- by encouraging preventive maintenance (systematic PS realignment during shutdowns, …)."

Recommendations:
Short term & Medium priority

- ***"…we consider as highly justified to implement a reduction of the basic period down to 0.9 s.*** "

- ***" …we recommend to increase the intensity of the CNGS type of beam in the SPS. This entails:***
  - to analyze the needs in all machines (RF, beam feedbacks, impedance reduction, …) and to define a precise improvement programme, preferably by the end of 2004. In particular ***the longitudinal impedance of the SPS ejection kickers is an identified limitation that we urge to improve as soon as possible***.
  - to start implementing it as soon as possible, profiting from the 2005 shutdown."

Recommendations: Medium term

"…we recommend to replace the 50 MeV proton linac 2 by a 160 MeV H- linac (linac 4). This requires:

- to actively pursue R. & D. on components and beam dynamics, to prepare a technical design report for the year 2006,
- to start its construction as soon as the necessary resources can be made available, if possible by the end of 2006 so that linac 2 could be replaced by the end of 2010."

Recommendations: Long term

- "… The selection of the optimum accelerator to build after linac 4 depends upon decisions which are not yet taken, about the future favored physics programmes at CERN. It is therefore impossible to specify it today."
- "… for the time-being, the SPL has the largest potential, which justifies pursuing the on-going study, especially of the low energy front end (linac 4) which is useful in all scenarios."

Summary of recommendations

- At short term, to define in 2004 and start in 2005 the 3 following projects:
  - new multi-turn ejection
  - increased intensity in the SPS for CNGS (implications in all machines)
  - 0.9 s basic period

Availability: start-up 2008
Cost (P+M): < 6.8 MCHF

Availability: start-up 2007 ?
Cost (P+M): ?

Availability: start-up 2006
Cost (P+M): ~ 1 MCHF

- At medium term, to work on the design of Linac 4, to prepare for a decision of construction at the end of 2006.

Covered with the budget already requested

- At long term, to prepare for a decision concerning the optimum future accelerator by pursuing the study of a Superconducting Proton Linac.

Covered with the budget already requested

ANNEXES

Beam loss (1)

Expected beam loss inventory for nominal CNGS beam			
Machine / process	**Intensity/cycle**	**Transmission**	**Losses/cycle**
CNGS target	$4.40\cdot10^{13}$		
SPS 400 GeV to target (fast extraction)		~100 %	negligible
400 GeV SPS	$4.40\cdot10^{13}$		
TT10 to SPS 400 GeV (two injections)		92 %	$3.8\cdot10^{12}$
TT2/TT10 (two batches)	$4.78\cdot10^{13}$		
Continuous Transfer PS to TT2 (two batches)		90 %	$5.3\cdot10^{12}$
PS 13 GeV (two batches)	$5.31\cdot10^{13}$		
PSB 1.4 GeV to PS 13 GeV (two batches)		92 %	$4.6\cdot10^{12}$
PSB 1.4 GeV (two batches)	$5.78\cdot10^{13}$		

Beam loss (2)

Comparison of integrated beam losses: nominal CNGS and 1998 fixed target operations			
Machine / Element	**Expected losses per year nominal CNGS 4700 hours operation**	**Integrated losses during 1998 FT run 3750 hours operation**	**Ratio of beam losses CNGS/1998 FT**
SPS complex overall (TT10 – SPS – targets)	$4.2 \cdot 10^{18}$	$2.8 \cdot 10^{18}$	1.51
SPS 450 (400) GeV – targets	negligible	$0.5 \cdot 10^{18}$	-
PS complex overall (PSB 1.4 GeV – PS – TT2)	$12.7 \cdot 10^{18}$	$6.9 \cdot 10^{18}$	1.84
PS electrostatic septum only (SEH 31)	$6.8 \cdot 10^{18}$	$3.7 \cdot 10^{18}$	1.84
All machines from PSB 1.4 GeV to SPS targets	$16.9 \cdot 10^{18}$	$9.7 \cdot 10^{18}$	1.75

Beam loss (3)

- FACTS:
  - The total amount of beam lost every year will be nearly twice the 1998 figure.
  - 40 % will occur at PS ejection.

- CONSEQUENCES:
  - Fast aging of equipment (e.g.: septum cable and oil)
    - ⇒ degradation of reliability
    - ⇒ frequent interventions
    - ⇒ personnel dose
  - Reduced access to more zones ?
  - Ring activation