PROPOSALS FOR THE UPGRADE OF THE CERN PROTON ACCELERATOR COMPLEX*

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

- Introduction
- Needs and means
- Analysis
- Recommendations
- Status of implementation
- Conclusion

Introduction

The HIP Working Group

- MEMBERS

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

- MANDATE
  - Define a list of specifications for beam performance based on perceived future physics needs.
  - Investigate possible changes to the CERN complex of proton accelerators.
  - Publish a summary of various alternatives and compare them in terms of performance, flexibility and approximate cost. A preferred scheme should be indicated with the possible option of a staged realisation.
  - Present recommendations to the A&B management by the end of 2003.

Work history

- Minutes and presentations (24 meetings between 01/03 and 03/04) 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 (editor)
- Intermediate reports at ATC (06/03), ISOLDE upgrade SG (09/03)
- Presentation of recommendations at ATC (02/04) and at various users communities [CNGS (01/04), COMPASS (07/04), …]
- Final report published (May 2004, CERN-AB-2004-022 OP/RF)

Subjects & interviewed persons

PERSONS	USERS' NEEDS	ACCELERATORS' ISSUES
S. Baird, M. Benedikt		Proton beam availability
T. Nilsson	ISOLDE	
M. Benedikt, G. Metral		Potential of shorter basic period
K. Elsener	CNGS	
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	
M. Hauschild, L. Gatignon	COMPASS	

Needs and means

Finding out the physics requests

- 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) , 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.

Summary of requests

USER	CERN COMMITMENT*	USERS' WISHES	
	Short term	Medium term *[~ asap !]*	Long term *[2014 and beyond]*
LHC	**Planned beams**	**Ultimate luminosity**	Luminosity upgrades
FT (COMPASS)	**7.2×10^{5} spills/y ?**	**7.2×10^{5} spills/y**	
CNGS	**4.5×10^{19} p/year**	Upgrade ~ $\times2$	
ISOLDE	**1.92 μA ****	Upgrade ~ $\times5$	
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

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

Analysis

Evaluation procedure*

*** Detailed in previous talk by M. Benedikt**

Operational assumptions

- Schedules

		2006		2007 - 2010			
		PSB/PS complex	SPS complex	PSB/PS complex	SPS complex		LHC
					2007*	2008-10	
Total running time with beam	[h]	6000	5500	6000	5500	5500	5000
Setup and dedicated MD	[h]	1500	1500	600	1000	800	-
Physics operation	[h]	4500	4000	5400	4500	4700	-
Effective physics hours	[h]	4050	3200	4860	3600	3760	-

- Operation modes: LHC filling, LHC set-up, CNGS-FT
- Distribution of SPS operation modes

SPS operation mode		2006	2007	2010
Physics operation	[h]	4000	4500	4700
LHC filling mode	[%]	0	15	5
LHC setup mode	[%]	0	35	10
CNGS – FT mode	[%]	100	50	85

Performance without upgrades*

* Detailed in previous talk by M. Benedikt

	2006	2007	2010	Basic user's request
CNGS flux [$\times10^{19}$ pot/year]	4.4*	4.2*	4.9*	4.5
FT spills [$\times10^{5}$ /year]	3.3	1.8	3.3	7.2
East Hall spills [$\times10^{6}$ /year]	1.3	2.3	2.3	2.3
NTOF flux [$\times10^{19}$ pot/year]	1.4	1.6	1.6	1.5
ISOLDE flux [μA] [nb. of pulses/hour]	1.84 1296	1.65 1160	1.74 1220	1.92 1350
72 bunch train for LHC at PS exit [$\times10^{11}$ ppb]	1.5	1.5	1.5	1.3 (2**)

* with important irradiation of PS equipment
** ultimate beam in LHC

Comments on upgrades

- Irradiation caused by beam loss at high intensity is a major concern (Details in the previous talk by M. Benedikt).

  ⇒ Importance of the new multi-turn ejection from the PS ("Island extraction") which is a promising means to reduce loss.

- 0.6 s basic period is much more expensive than 0.9 s and would severely limit the flexibility of the PSB.

  ⇒ 0.9s is a valuable compromise for a reduced PSB repetition period.

- **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…].

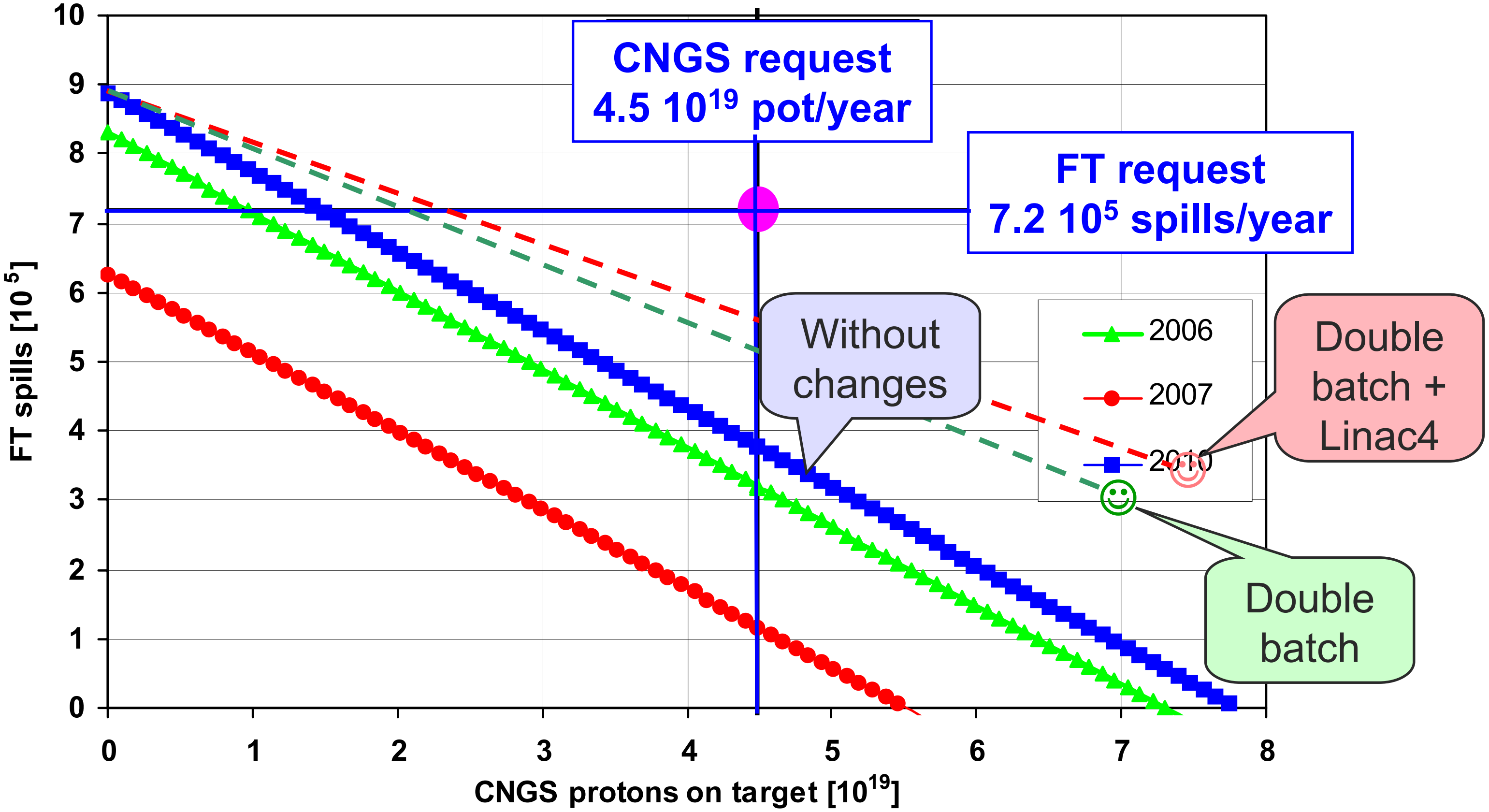
Estimated performance with the recommended upgrades

Performance in 2010 with (i) a PSB repetition period of 0.9 s, (ii) 7 10^{13} ppp in the SPS and (iii) Linac4 injecting in the PSB

	(i)	(i)+(ii)	(i)+(ii)+(iii)	
	Standard operation	**CNGS double batch**	**Linac 4**	**Basic user's request**
CNGS flux [$\times 10^{19}$ pot/year]	4.7 (4.5)	7.0 (4.5)	7.5 (4.5)	4.5
FT spills [$\times 10^{5}$ /year]	3.2 (3.4)	3.0 (5.1)	3.2 (5.6)	7.2
East Hall spills [$\times 10^{6}$ /year]	2.3	2.3	2.3	2.3
NTOF flux [$\times 10^{19}$ pot/year]	1.7	1.6	1.7	1.5
ISOLDE flux [μA] **[nb. of pulses/hour]**	3.0 2126	2.45 1722	6.2 2160	1.9 1350
72 bunch train for LHC at PS exit [$\times 10^{11}$ ppb]	1.5	1.5	2	1.3 (2*)

* ultimate

FT versus CNGS performance



CNGS and FT (COMPASS) share the available SPS cycles:

⇒ they cannot be satisfied simultaneously.

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 + beta-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 (30-50 GeV)	Valuable	Very interesting for neutrino factory	No	Valuable
New PS (30-50 GeV)	Valuable	No	No	Valuable
1 TeV LHC injector	Very interesting for luminosity upgrade. Essential for doubling the LHC energy	No	No	Valuable

Recommendations

Summary

↔

- In the short term, to define in 2004 and start in 2005 the 3 following projects:
  - **New multi-turn ejection for the PS.**
  - **Increased intensity in the SPS for CNGS (implications in all machines).**
  - **0.9 s PSB repetition time.**

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

- In the long term, to prepare for a decision concerning the optimum future accelerator by pursuing the **study of a Superconducting Proton Linac** and by exploring **alternative scenarios for the LHC upgrade**.

Status of implementation

Short term projects

- Three studies have been approved on March 1,2004 by the AB management to prepare detailed proposals for the three short term projects.
- Project proposals are due to be submitted in December 2004 (technical description and resources).
- For a maximum benefit, decisions have to be taken as soon as possible (January 2005).

	Leader	**MDs**	**Full implementation (preliminary…)**
PS islands extraction (P1)	M. Benedikt	2004 (all year): proof of principle	2008
Increased PSB repetition rate (P2)	M. Giovannozzi	2005 (Linacs + PSB): demonstration	Start-up 2006
Increased intensity per pulse for CNGS (P3)	E. Chapochnikova	2004 (w37-40): assess present status/limitations To be continued until 2009	Test during MDs Operational benefit after P1 (~ 2009)

Medium term: Linac 4

- Study in progress.
  Core team: ***R. Garoby***, K. Hanke, A. Lombardi, C. Rossi, M. Vretenar,

- Supported by:
  - IPHI collaboration (CEA + IN2P3)
  - HIPPI (EU FP6)
  - ISTC (Projects #2875, 2888 and 2889)

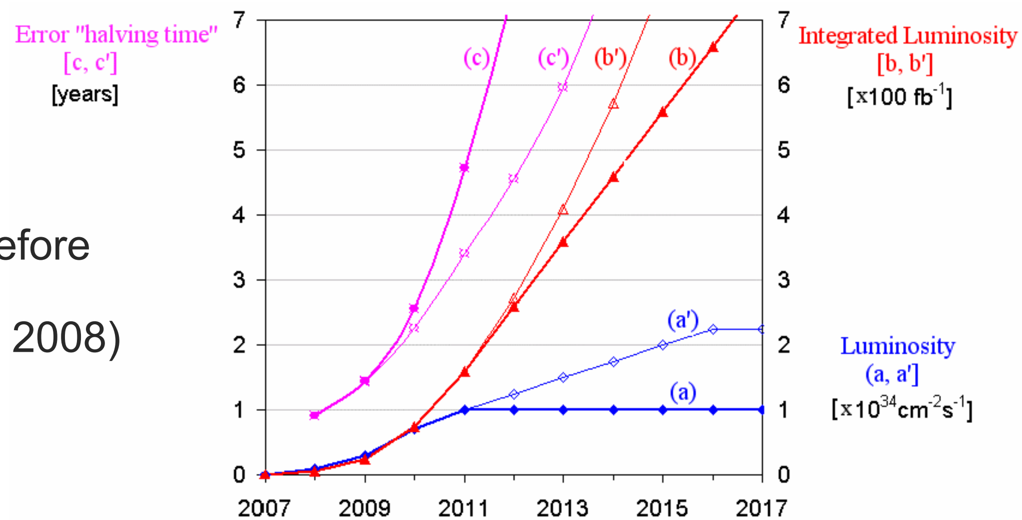
- Planning of the approved study:
  - 3 MeV test place: 2007
  - Technical Design Report (Project Proposal): mid-2006

- Project planning:
  - approval: expected early in 2007 …
  - Start-up: mid-2010
  - Operation for physics: early in 2011

Long term options

- Contributing activities:
  - BENE ["Beams for European Neutrino Experiments"] (EU FP6)
  - HEHIHB ["High Energy, High Intensity, High Brightness" accelerators] (EU FP6)
  - LHC upgrade studies
  - EURISOL Design Study (EU FP6)
- Options studied:
  - SPL through Linac 4 + minor additions. Conceptual Design Report 2: mid-2005
  - Slow cycling synchrotrons using superconducting magnets through collaboration with FAIR (GSI)

- Need for decisions ~ 6 years before the LHC stops for upgrade
(upgrade in 2014 ⇒ decision in 2008)



Conclusions

- In the short/medium term (~ 2010): Shortage of proton beams for the approved users (worse if their expected upgrades are taken into account…) and risk with beam loss / hardware activation

  ⇒ Need for:
  - **implementing improvements as soon as possible**
  - **arbitration between users…**

- In the long term = Future of proton accelerators at CERN

  - LHC will operate until ~ 2020

  ⇒ Consolidation + LHC upgrade

  - LHC will always be a part-time user of the injector complex

  ⇒ Other physics programmes can be authorized if they are compatible with LHC needs and (better !) if they share the cost of the upgrades

ANNEX 1
Detailed 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."

↔

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 (Project 1),***
- 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, …)."

↔

Short term & Medium priority

- ***"…we consider as highly justified to implement a reduction of the basic period down to 0.9 s. " (Project 2)***

- ***" …we recommend to increase the intensity of the CNGS type of beam in the SPS. (Project 3) 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."

↔

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."

↔

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."**

↔

ANNEX 2

Brightness for LHC

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}	$\mathbf{1.3 \times 10^{11}}$
PS ultimate (estimate)	1.7×10^{11}	$\mathbf{2 \times 10^{11}}$
PS max. (experimental)		$\mathbf{1.4 \times 10^{11}}$

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}	$\mathbf{2 \times 10^{11}}$	3×10^{11}
Nb. of bunches / PS pulse	42 (48)	**72**	48
PS repetition period	3 BP	**2 BP**	2 BP

ANNEX 3

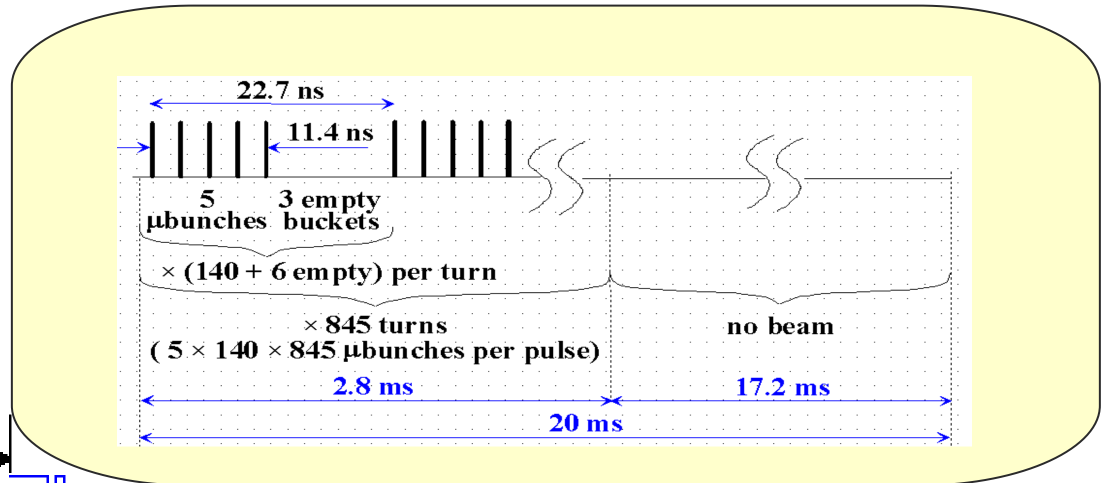
THE SPL

SPL beam characteristics (CDR 1)

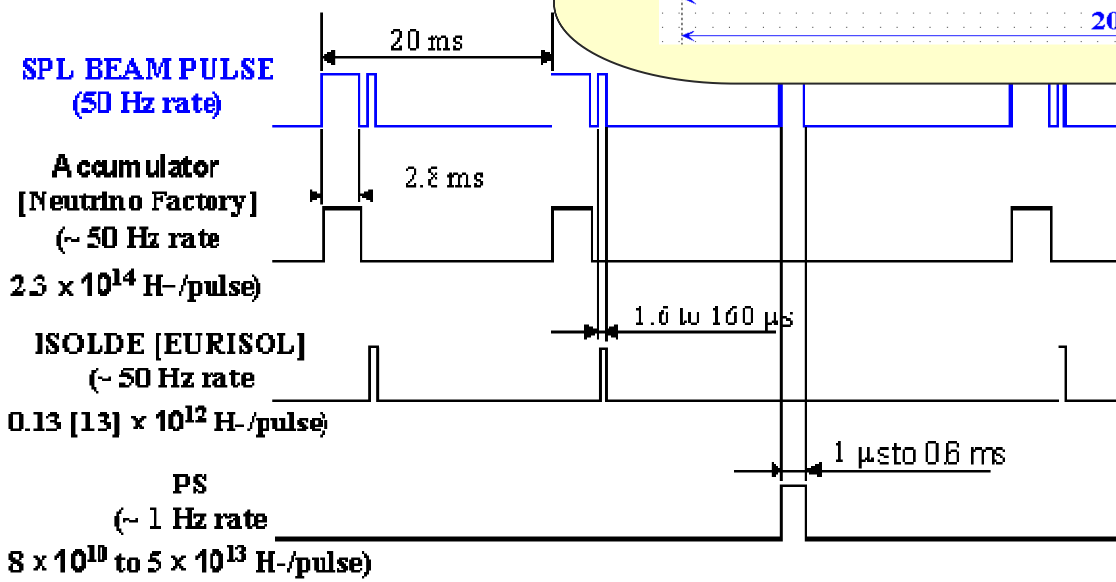
Ion species	H^-	
Kinetic energy	2.2	GeV
Mean current during the pulse	13	mA
Duty cycle	14	%
Mean beam power	4	MW
Pulse repetition rate	50	Hz
Pulse duration	2.8	ms
Bunch frequency (minimum distance between bunches)	352.2	MHz
Duty cycle during the pulse (nb. of bunches/nb. of buckets)	62 (5/8)	%
Number of protons per bunch	$4.02\ 10^8$	
Normalized rms transverse emittances	0.4	π mm mrad
Longitudinal rms emittance	0.3	π deg MeV
Bunch length (at accumulator input)	0.5	ns
Energy spread (at accumulator input)	0.5	MeV
Energy jitter during the beam pulse	< ± 0.2	MeV
Energy jitter between pulses	< ± 2	MeV

SPL beam time structure (CDR 1)

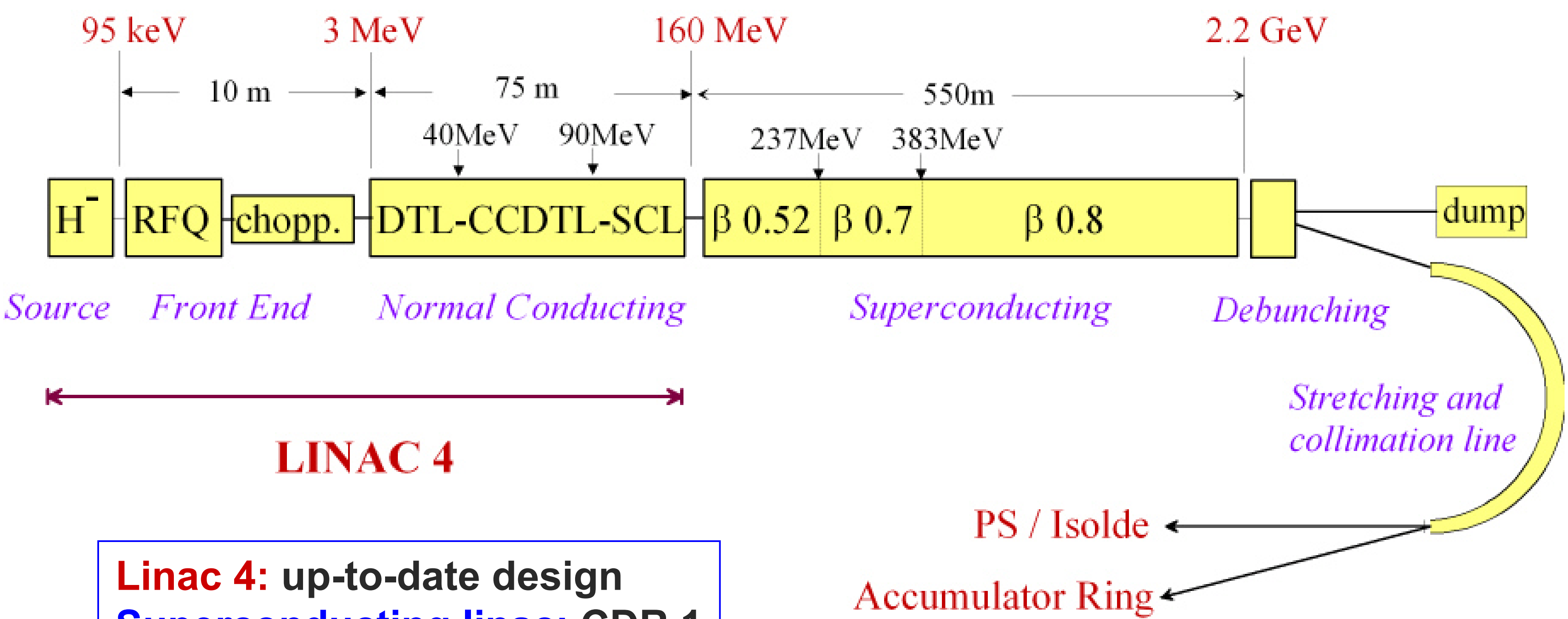
Fine time structure (within pulse)



Macro time structure



SPL block diagram (CDR 1)

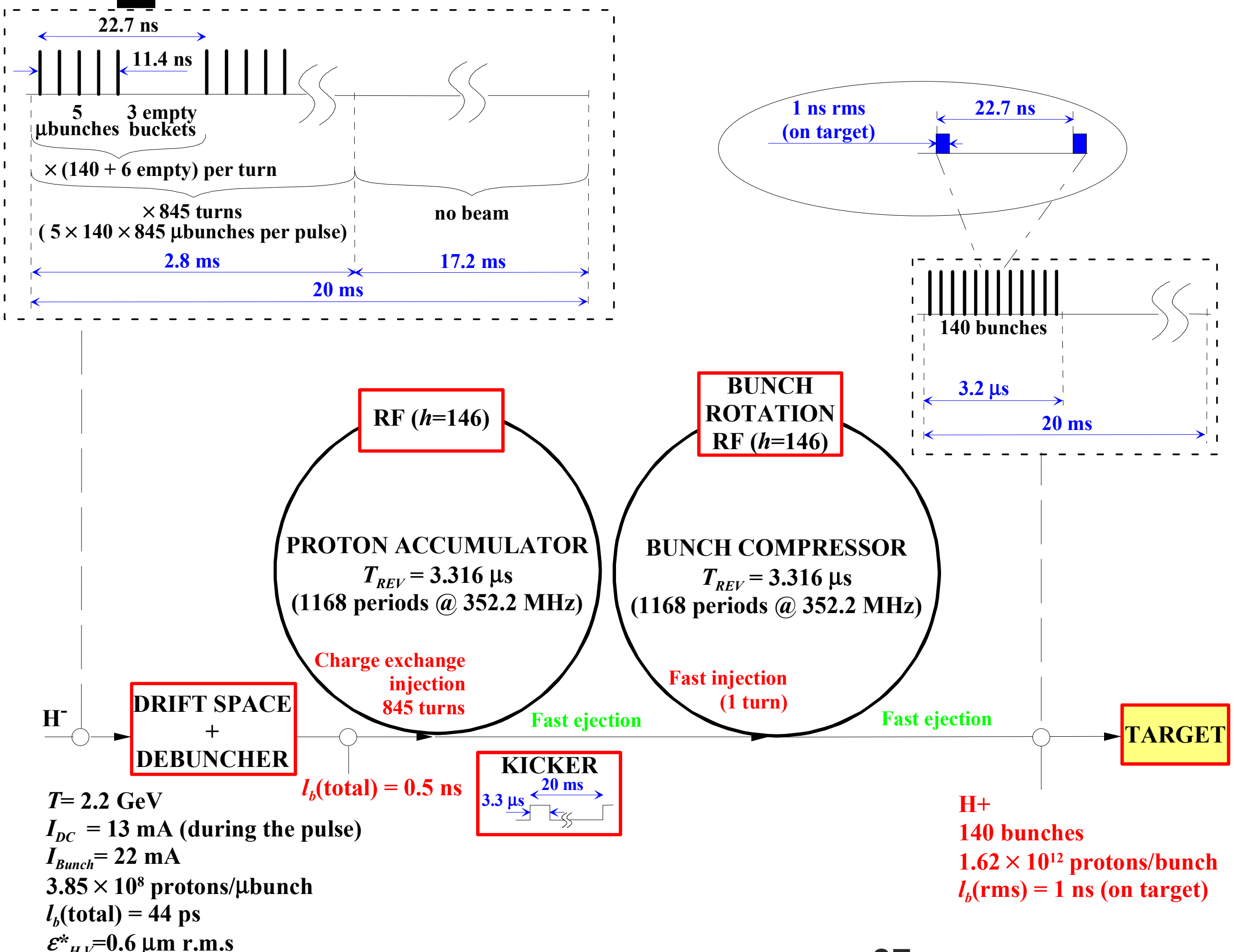


Linac 4: up-to-date design
Superconducting linac: CDR 1

SPL acceleration systems (CDR 1)

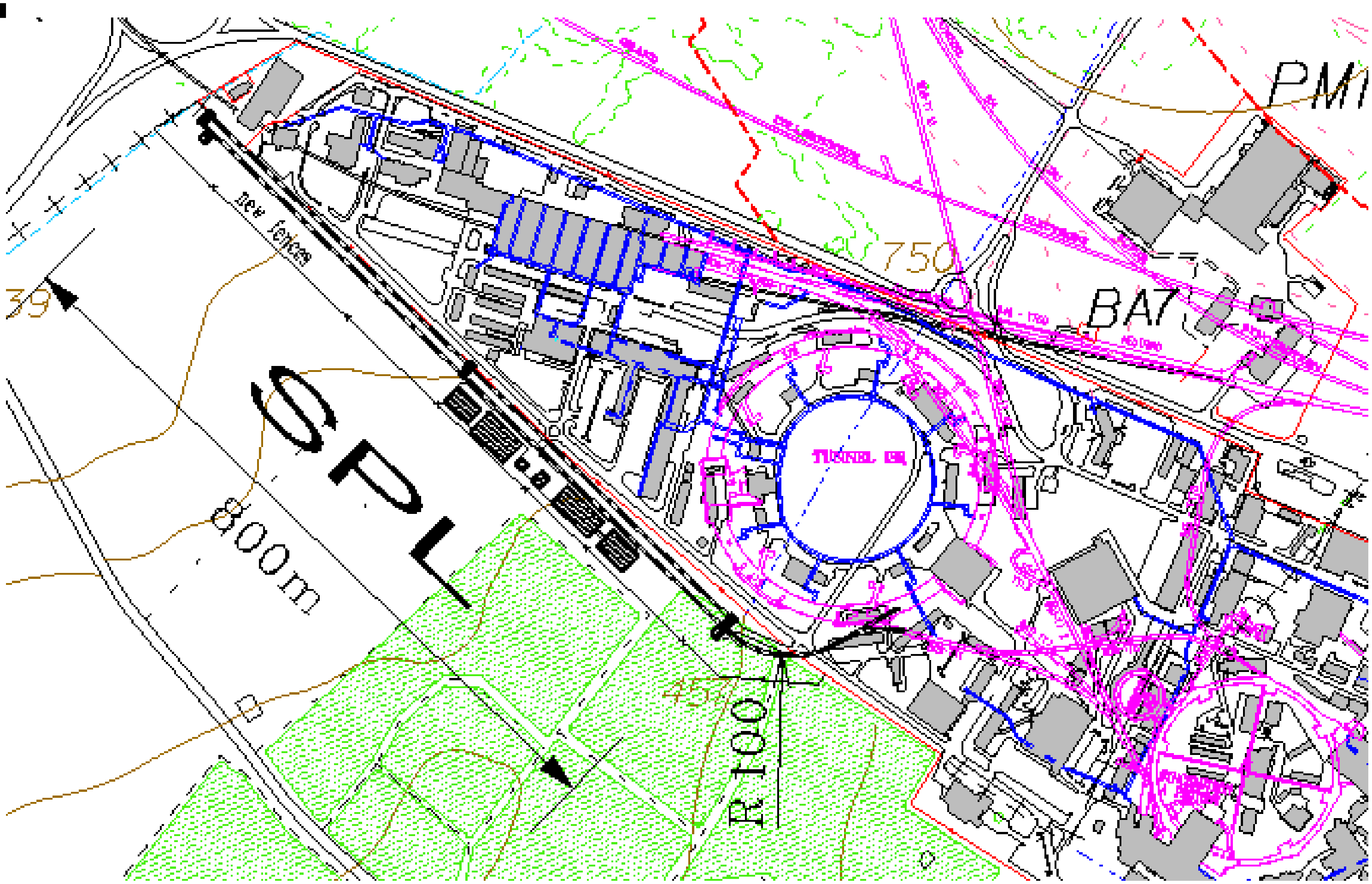
Section	Input energy (MeV)	Output energy (MeV)	Nb. of cavities	Peak RF power (MW)	Nb. of klystrons	Nb. of tetrodes	Nb. of Quads	Length (m)
LEBT	-	0.095	-	-	-	-	-	2
RFQ	0.095	3	1	0.9	1	-	-	6
Chopper line	3	3	3	0.1	-	3	6	3.7
DTL	3	40	3	4.1	5	-	111	16.7
CCDTL	40	90	27	4.8	6	-	28	30.1
SCL	90	160	20	12.6	5	-	21	27.8
β=0.52	160	236	27	1	-	28	9	67
β=0.7	236	383	32	1.9	-	32	16	80
β=0.8 I	383	1111	52	9.5	13	-	26	166
β=0.8 II	1111	2235	76	14.6	19	-	19	237
Debunching	2235	2235	4	-	1	-	2	13
Total			245	49.5	50	63	238	649.3

Accumulator and Compressor

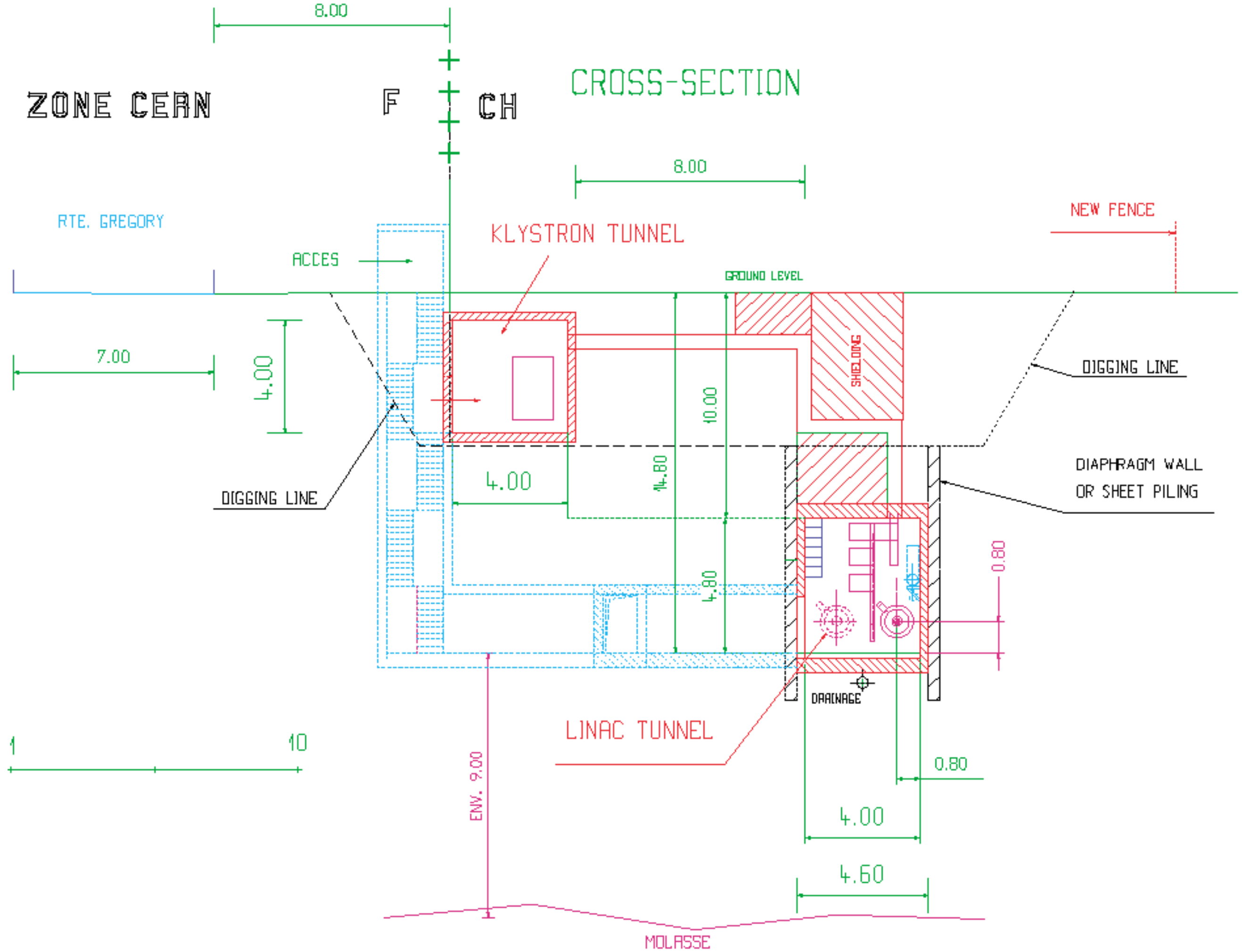


Parameter	Value	Unit
Mean beam power	**4**	MW
Kinetic energy	**2.2**	GeV
Repetiton rate	**50**	Hz
Pulse duration	**3.3**	µs
Number of bunches	**140**	
Pulse intensity	**2.27 ×10^{14}**	p/pulse
Bunch spacing (Bunch frequency)	**22.7 (44)**	ns (MHz)
Bunch length (σ)	**1**	ns
Relative momentum spread (σ)	**5×10^{-3}**	
Norm. horizontal emittance (σ)	**50**	µm.rad

Layout (CDR 1)



SPL cross section (CDR 1)



SPL on the CERN site