The SPL* at CERN: characteristics and potential

* Superconducting Proton Linac

- Introduction
- Description
- Performance of the accelerator complex
- Status of development
- Roadmap
- Final word

R. Garoby for the SPL study team
and the HIP Working Group

"Physics with a multi-MW proton source"
25-27 May, 2004

INTRODUCTION

Contributors

- **SPL Study**

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- **HIP working group**

  M. Benedikt, K. Cornelis, R. Garoby, E. Metral, F. Ruggiero, M. Vretenar

- **IPHI-SPL COLLABORATION**

  CEA (DSM/DAPNIA @ Saclay) + CNRS (IN2P3 @ Orsay & Grenoble)

- **HIPPI JRA (inside CARE, supported by the European Union)**

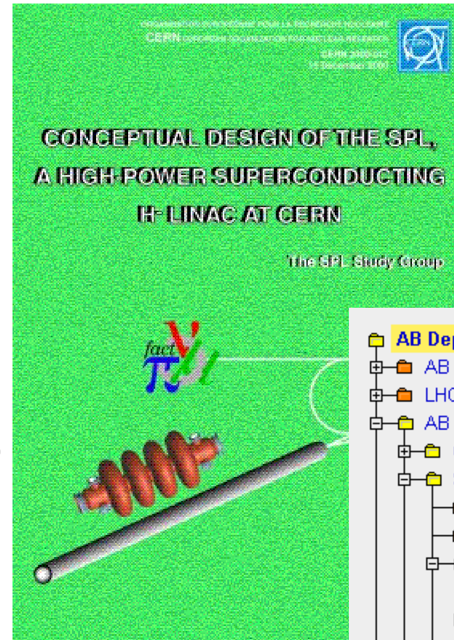
  CEA (F), CERN (CH), Frankfurt University (D), GSI (D), INFN-Milano (I), IN2P3 (F), RAL (GB), KFZ Juelich (D)

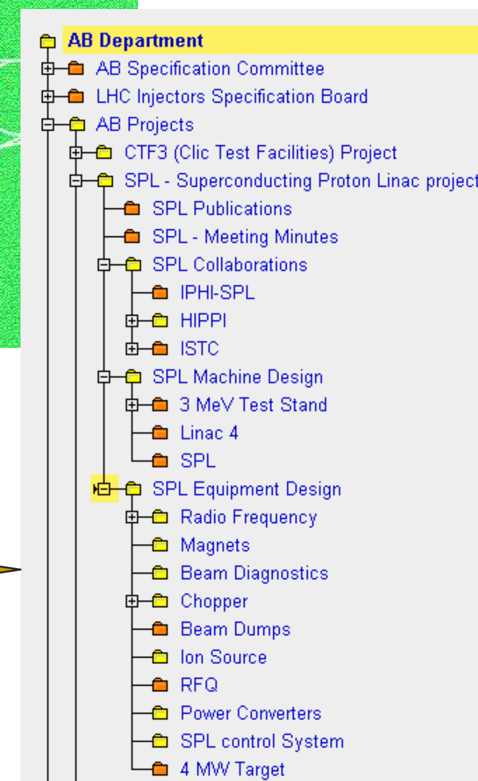
- **ISTC projects #2875, 2888 and 2889**

  BINP (Novosibirsk), IHEP (Protvino), IHEP (Moscow), VNIIEF (Sarov), VNIITF (Snezinsk)

Context & References

- Present characteristics (Conceptual Design Report 1):
  - are “optimized” for a neutrino factory
  - assume the use of LEP cavities & klystrons up to the highest energy
- Update is planned (CDR 2):
  - based on requests from this workshop
  - using 704 MHz RF and bulk Niobium cavities
  - in collaboration with CEA-Saclay & INFN-Mlano
  - to be published in mid-2005
- Up-to-date information is available:
  - on the CERN EDMS
  - on the SPL site: **http://ps-div.web.cern.ch/ps-div/SPL_SG/**





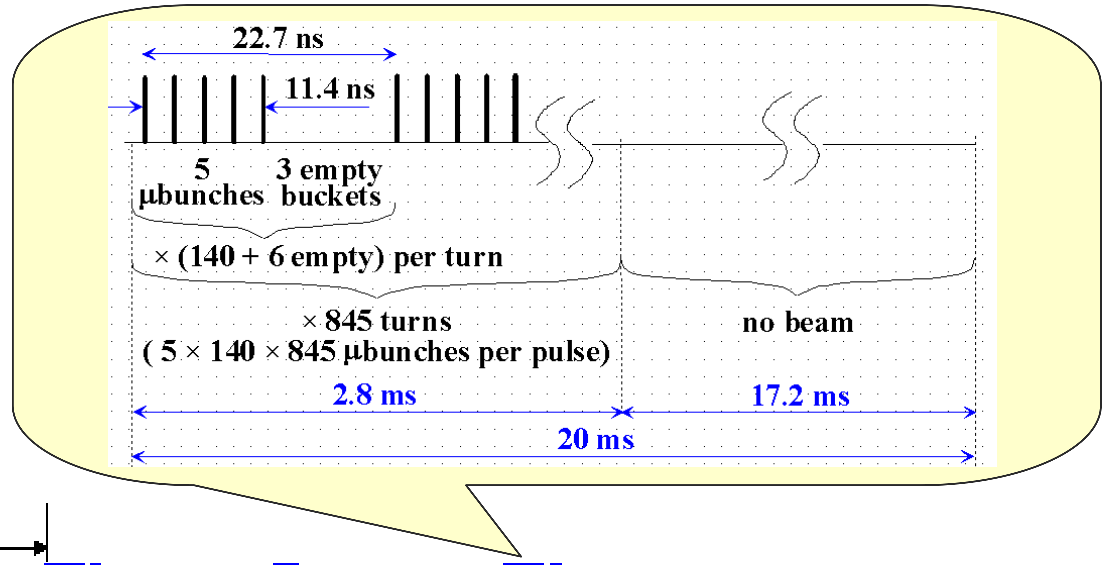
DESCRIPTION

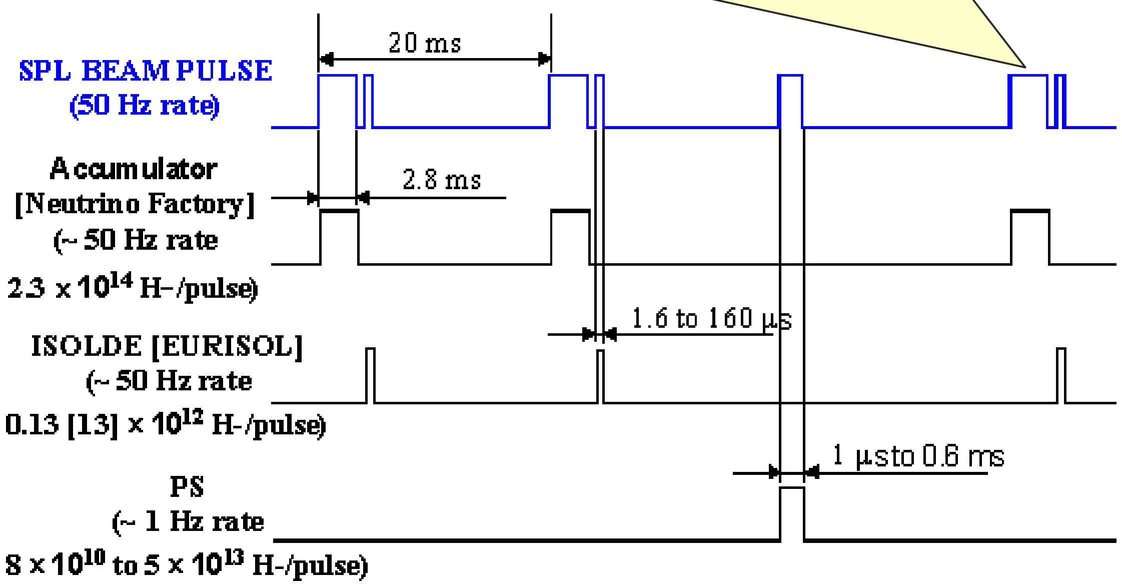
SPL beam characteristics (CDR 1)

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)

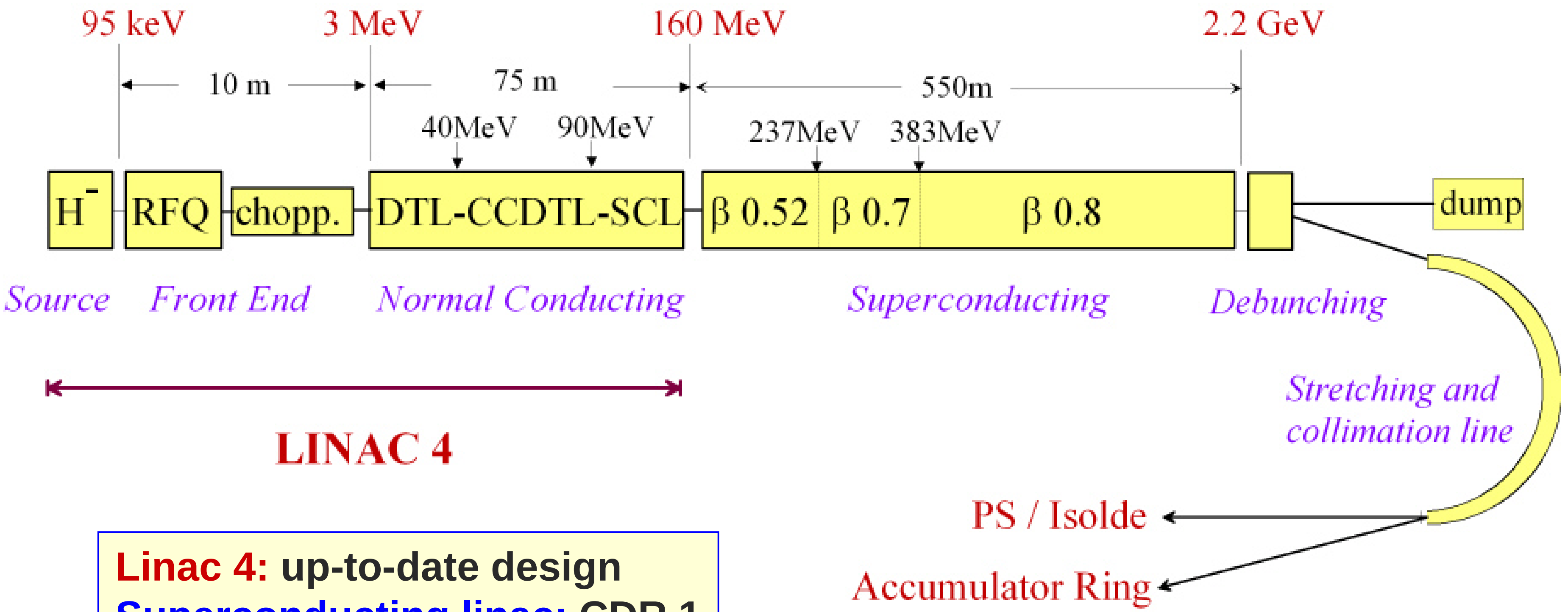
Fine time structure (within pulse)





Macro time structure

SPL block diagram (CDR 1)

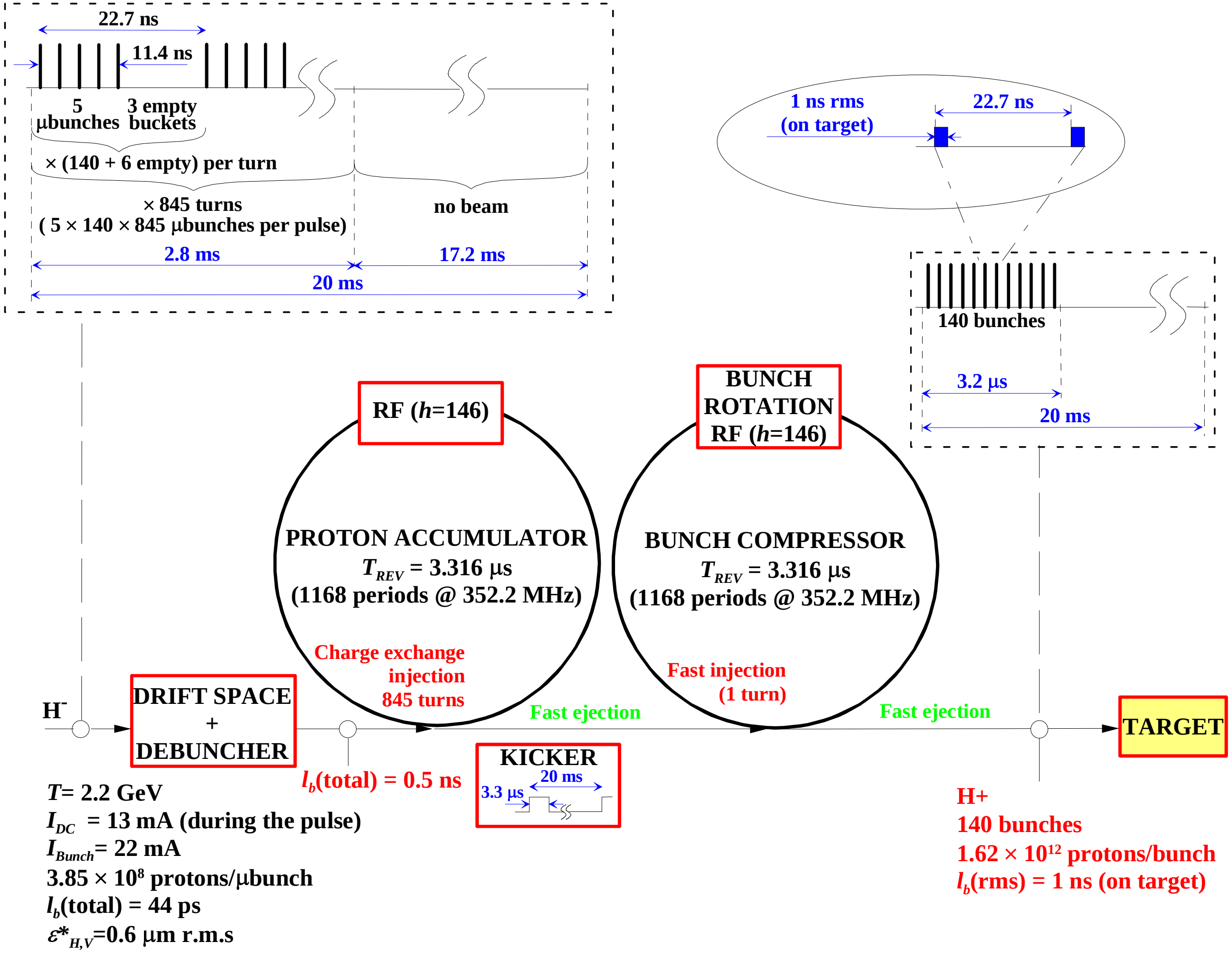


Linac 4: up-to-date design
Superconducting linac: CDR 1

SPL acceleration systems (CDR 1)

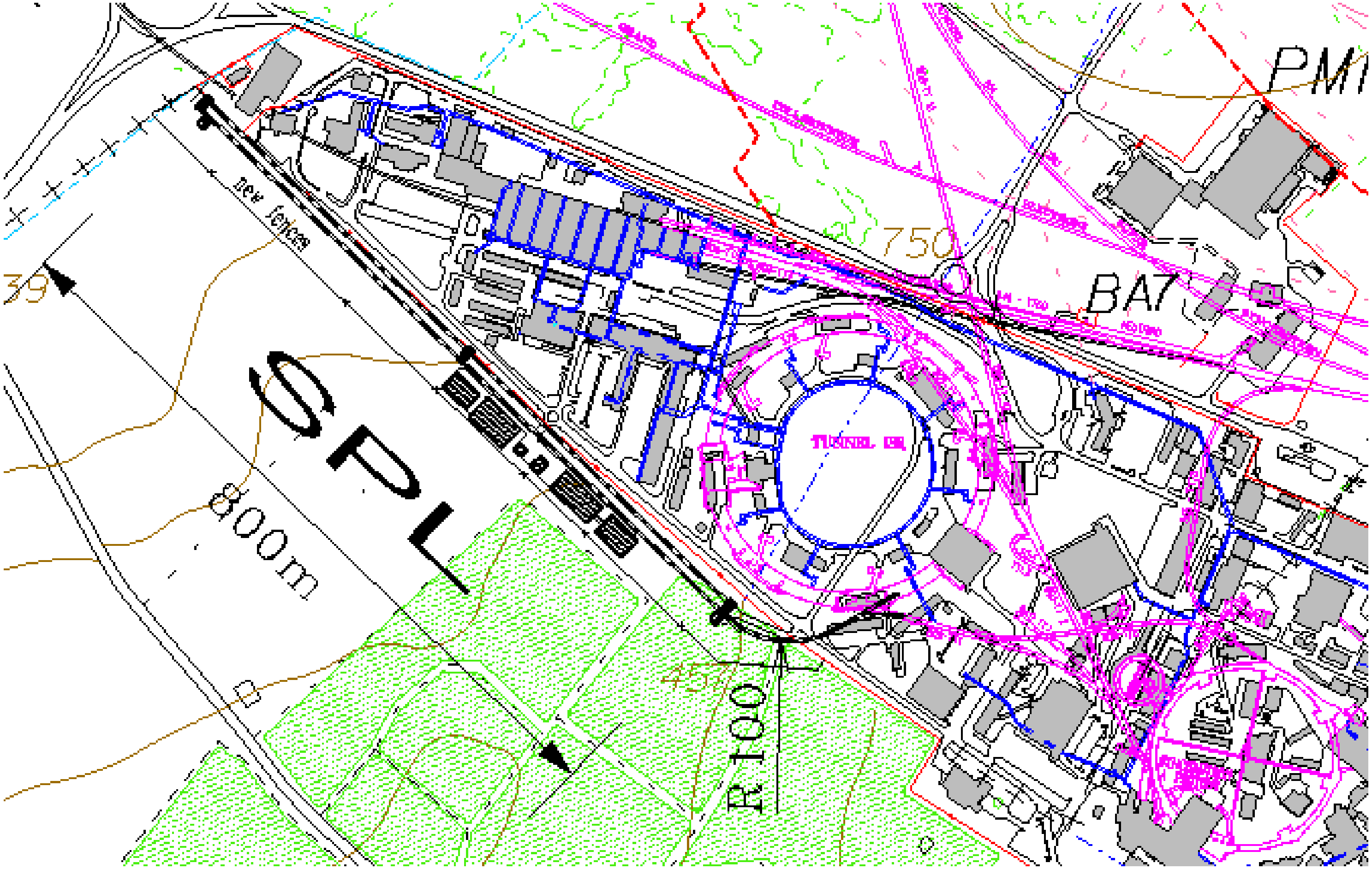
Section	Input energy (MeV)	Output energy (MeV)	Nb. of cavities	Peak RF power (MW)	Nb. of klystrons	Nb. of tetrodes	Nb. of Quads	Length (m)
LEBT	-	0.095	-	-	-	-	-	2
RFQ	0.095	3	1	0.9	1	-	-	6
Chopper line	3	3	3	0.1	-	3	6	3.7
DTL	3	40	3	4.1	5	-	111	16.7
CCDTL	40	90	27	4.8	6	-	28	30.1
SCL	90	160	20	12.6	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

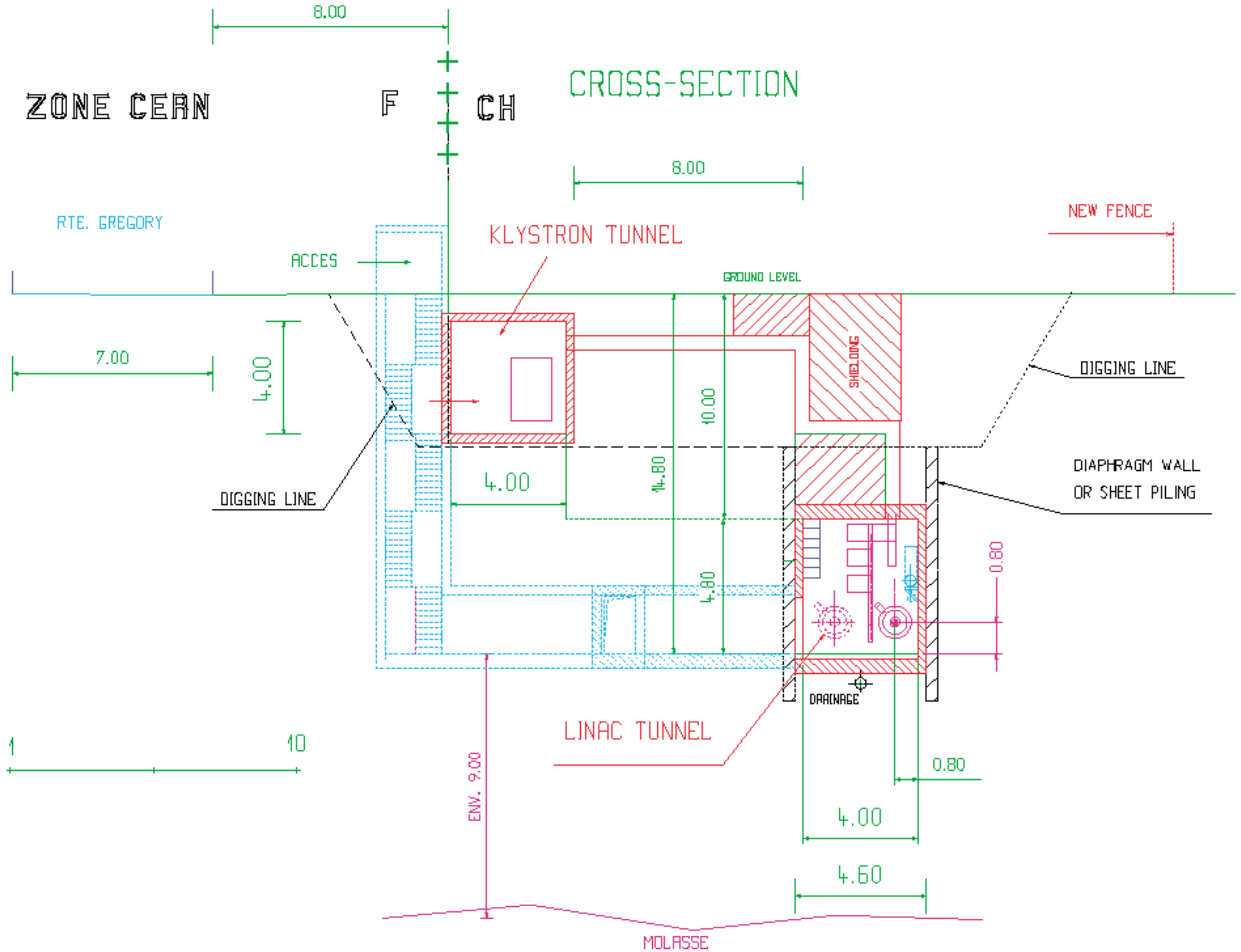


Parameter	Value	Unit
Mean beam power	4	MW
Kinetic energy	2.2	GeV
Repetiton rate	50	Hz
Pulse duration	3.3	µs
Number of bunches	140	
Pulse intensity	2.27 $\times 10^{14}$	p/pulse
Bunch spacing (Bunch frequency)	22.7 (44)	ns (MHz)
Bunch length (σ)	1	ns
Relative momentum spread (σ)	5×10^{-3}	
Norm. horizontal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

Layout (CDR 1)



SPL cross section (CDR 1)



PERFORMANCE OF THE ACCELERATOR COMPLEX

Identified users' requests[1]

USER	CERN COMMITMENT	USERS' WISHES	
	Short term	Medium term [~ asap !]	Long term ** [beyond 2014]
LHC	Planned beams	Ultimate luminosity	Luminosity upgrades
FT (COMPASS)	4.3⑨$10^5$ spills/y ?	7.2⑨$10^5$ spills/y	
CNGS	4.5⑨$10^{19}$ p/year	Upgrade ~ ⑨ 2	
ISOLDE	1.92 μA *	Upgrade ~ ⑨ 5	
Future ■ beams			> 2 GeV / 4 MW
EURISOL			1-2 GeV / 5 MW

* 1350 pulses/h – 3.2⑨$10^{13}$ ppp

** To be complemented during this workshop

[1]: assembled by the "High Intensity Protons" working group.
[CERN/AB working group mandated to (i) collect the present and foreseeable needs for high-intensity proton beams, (ii) analyze the capabilities of the CERN accelerator complex, (iii) compare possible improvements and (iv) recommend an upgrade path.]
"Report of the High Intensity Proton Working Group", CERN-AB-2004-022 OP/RF

SUMMARY OF RECOMMENDATIONS

- 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.

Medium term: potential 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) Standard operation	(i)+(ii) CNGS double batch	(i)+(ii)+(iii) 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)	3.3 (5.6)	7.2
East Hall spills [$\times 10^{6}$ /year]	1.5	1.4	1.5	1.3
NTOF flux [$\times 10^{19}$ pot/year]	1.6	1.5	1.6	1.5
ISOLDE flux [μA] [nb. of pulses/hour]	3.1 2200	2.6 1810	6.4 2240	1.9 1350
72 bunch train for LHC at PS exit [$\times 10^{11}$ ppb]	1.5	1.5	2	1.3 (2*)

* ultimate

Benefits of the SPL

Replacement of the (40 years old !) 1.4 GeV PSB by a 2.2 GeV SPL

⇓

☺ **Radio-active ion beams: EURISOL is feasible**

(direct use of 5-100 % of the SPL nominal beam)

☺ **Neutrino super-beam: ideal with a large detector at Frejus**

(using an accumulator and 100 % of the SPL nominal beam)

☺ **Neutrino beta-beam: ideal + synergy with EURISOL**

(direct use of 5 % of the SPL nominal beam)

☺ **LHC:**
- **potential for substantial increase of brightness/intensity from the PS beyond the ultimate (space charge limit is raised to 4 10^{11} ppb)***
- **large flexibility for # bunch spacings (replacing RF systems…)**
- **simplified operation / increased reliability**

😐 **PS:**
- **limited benefit on peak intensity (~ 6 10^{13} ppp)**
- **large potential for higher beam brightness (x 2)**
- **large flexibility in number of bunches, emittances and intensities**

😐 **CNGS: limited benefit (target capability is fully used with 7 10^{13} ppp)**

*** More work is needed to analyse the other limitations**

SPL potential

- More users can easily be supplied with protons
- Beam characteristics can still be adapted (energy, power, …)
- The SPL is an outstanding injector for any future synchrotron
- In a context of renovation of the injector complex, it makes sense to begin with the low energy accelerators, because:
  - the low energy machines are the oldest (problems with maintenance and performance)
  - beam brightness is defined at low energy
  - further accelerators can be based on a high performance injector (balanced accelerator cascade)

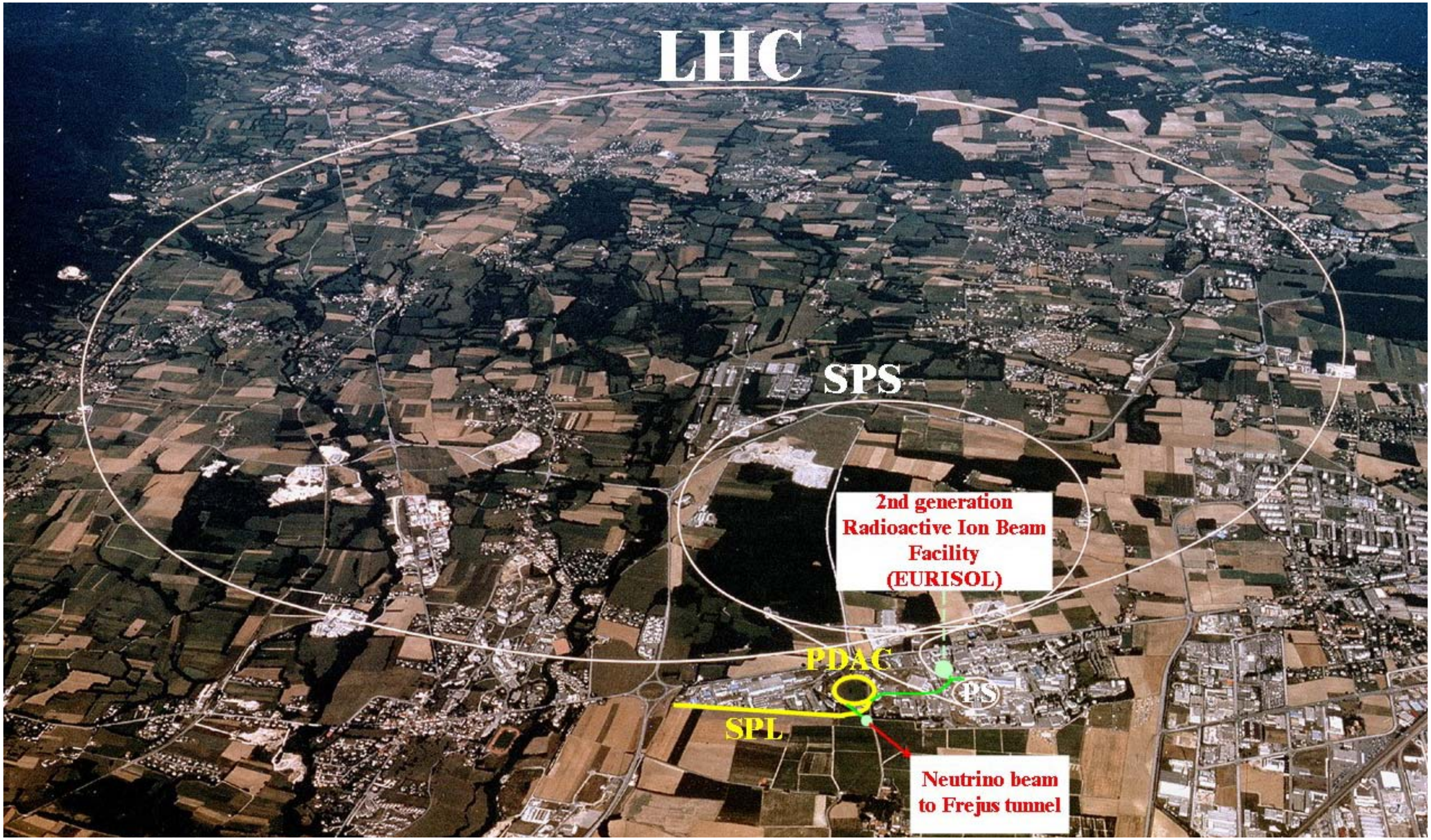
Long term: preliminary comparison

	INTEREST FOR			
	LHC upgrade	Neutrino physics beyond CNGS	Radioactive ion beams (EURISOL)	Others **
SPL * (>2 GeV – 50 Hz)	Valuable	Very interesting for super-beam + beta-beam	Ideal	Spare flux $\Rightarrow$ possibility to serve more users
RCS (30 GeV – 8 Hz)	Valuable	Very interesting for neutrino factory	No	Valuable
New PS (30 GeV)	Valuable	No	No	Valuable
New LHC injector (1 TeV)	Very interesting for doubling the LHC energy	No	No	Potential interest for kaon physics

* Comparison should also be made with an RCS of similar characteristics.

** Input expected from the present workshop !

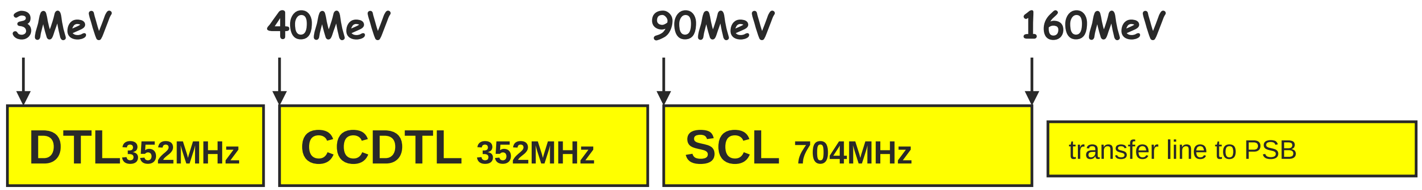
SPL on the CERN site



STATUS OF DEVELOPMENT

Evolution of the SPL Design

- **Linac 4**



  - **Energy is increased to 160 MeV** (result of extensive simulation, with space charge, of injection, accumulation and acceleration in the PSB)
  - High energy section (> 90 MeV) operates at **704 MHz** to fit inside the available space (higher gradients & higher power pulsed klystrons) and to prepare for a superconducting linac section at that frequency.
- **SPL**
  - Considering that the LEP cavities and their technology are aging, that CERN management does not support it anymore and that the corresponding know-how is disappearing, while bulk Nb is supported by other laboratories and provides higher gradients, the choice has been made to base the future design of the SPL on **704 MHz bulk Nb resonators**. **No superconducting LEP cavities will be used anymore.**
  - A new conceptual design will be prepared in 2004. **CEA and INFN (Milano) have agreed to contribute.** The energy will be optimized as a function of the physics goals.

➔3 MeV test place

Collaborations (1/3)

"Injecteur de Protons de Haute Intensité" (in French)

IPHI - CERN collaboration

Collaboration between CEA-Saclay / IN2P3 / CERN

Goal: Build a 3 MeV RFQ to be tested in CW with 100 mA beam current at Saclay in 2006 and delivered at CERN at the beginning of 2007 for the 3 MeV test place (pre-injector of the future linac 4 & SPL)

First 1 m section

"High Intensity Protons Pulsed Injectors"

Collaborations (2/3)

HIPPI inside CARE

6th Framework Program Integrating Activities CARE project Coordinated Accelerator Research in Europe for Particle Physics

"Joint Research Activity" supported by the European Union in the 6th Framework programme

- **Main Objectives**

  R&D of the technology for high intensity pulsed proton linear accelerators up to an energy of 200 MeV ⇒ Improvement of existing facilities (E.U. request) at GSI, RAL and CERN

- **Means**

  9 laboratories: RAL, CEA (Saclay), CERN, FZJ, GSI, Frankfurt University, INFN-Milano, IPN (Orsay), LPSC (Grenoble).
  11.1 MEuros + 3.6 MEuros (E.U.) over 5 years (2004 – 2008)

- **Organization ⇒ 5 Work Packages**
  - **WP1 : Management & Coordination (R. Garoby – CERN)**
  - **WP2 : Normal Conducting structures (J.M. Deconto – LPSC Grenoble)**
  - **WP3 : Superconducting structures (S. Chel – CEA Saclay)**
  - **WP4 : Beam chopper (A. Lombardi – CERN)**
  - **WP5 : Beam dynamics (I. Hoffmann – GSI)**

Collaborations (3/3)

ISTC projects for Linac 4 & SPL

Common features:
- One institute competent in accelerators + one nuclear city
- 2 years duration
- Design and construction of a prototype for high power tests at CERN

#2875 – BINP (Novossibirsk) + VNIITF (Snezinsk)

- Subject: Coupled Cavity Drift Tube Linac (CCDTL) structure (40-100 MeV) + cold model of SCL structure (100-200 MeV)
- Cost: k$ 550 (10805 man.days)
- Status: active since October 2003
- Prototype delivery: end 2005

#2888 – ITEP (Moscow) + VNIIEF (Sarov)

- Subject: Drift Tube Linac (DTL) structure with magnetic focusing ("Alvarez") (3-40 MeV)
- Cost: k$ 498 (? Man.days)
- Status: active since April 2004
- Prototype delivery: summer 2006

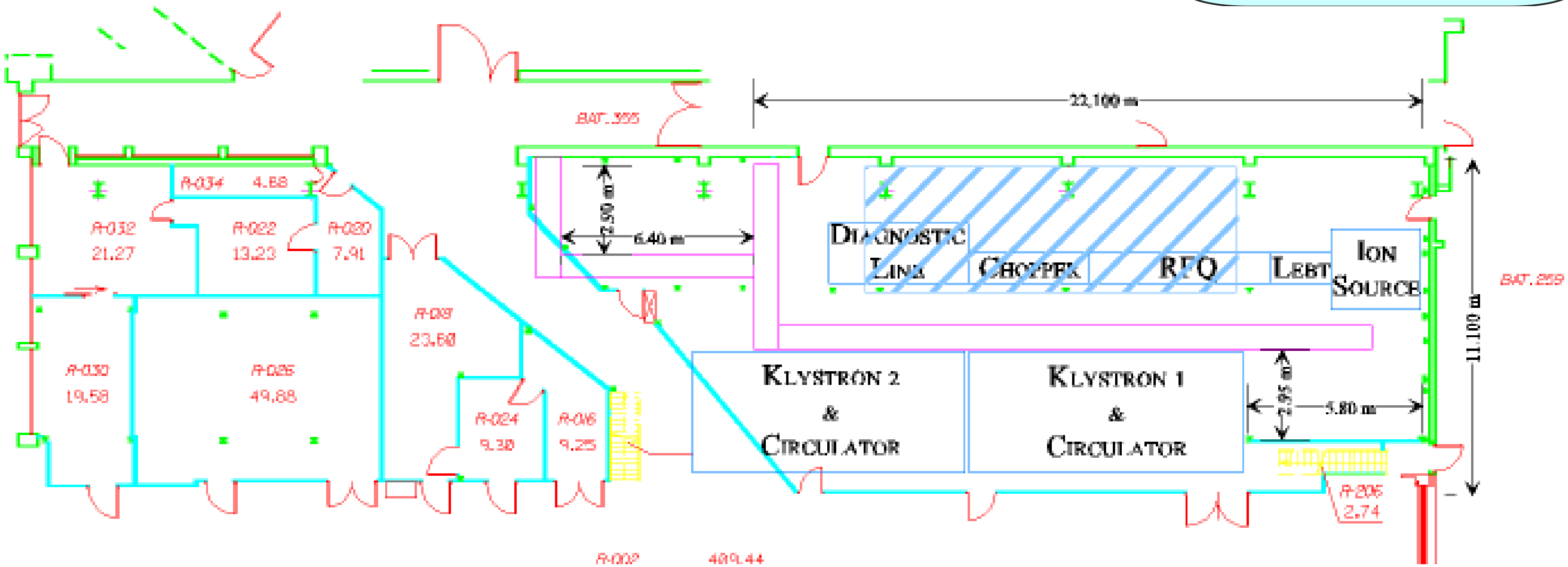
#2889 - IHEP (Protvino)+ VNIIEF (Sarov)

- Subject: DTL structure with focusing by RF quadrupoles (DTL-RFQ) (3-40 MeV)
- Cost: k$ 500 (8399 man.days)
- Status: active since April 2004
- Prototype delivery: summer 2006

Progress towards Linac4 (1/4)

3 MeV and RF test place

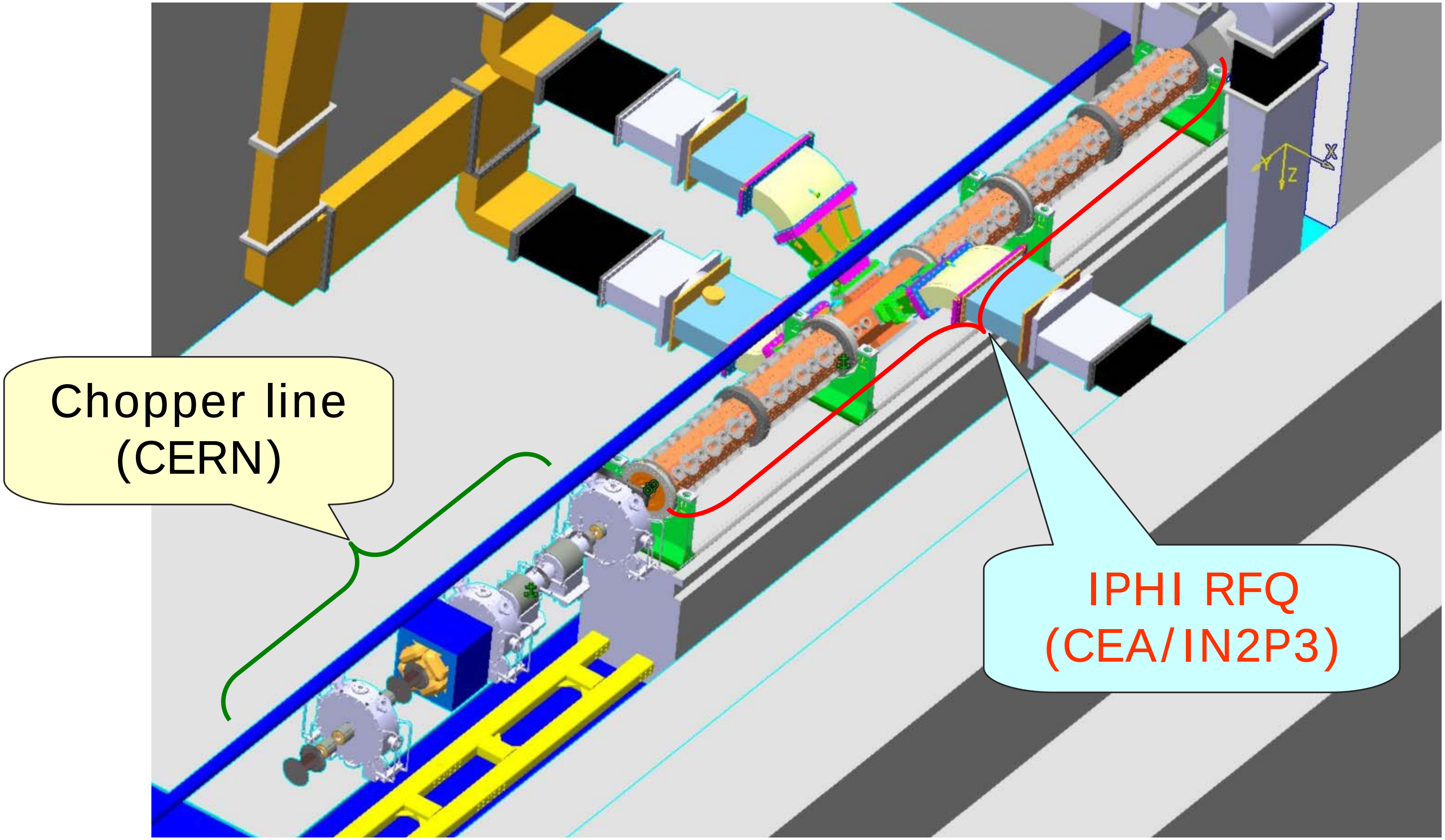
Poster on Wednesday 26, May



- 3 MeV Test Stand to be installed in the PS South Hall (in place for linac 4)
- Purpose: test essential front-end issues (hardware & beam dynamics)
- Made of IPHI RFQ + CERN chopper line + IN2P3 diagnostics line + 2 LEP klystrons (1 for the RFQ + 1 for testing other RF structures).
- Initial use of a standard CERN proton source, to be replaced by an H- source.
- The elements will be placed in the exact position foreseen for Linac4.
- ***Operation with beam: 2007***

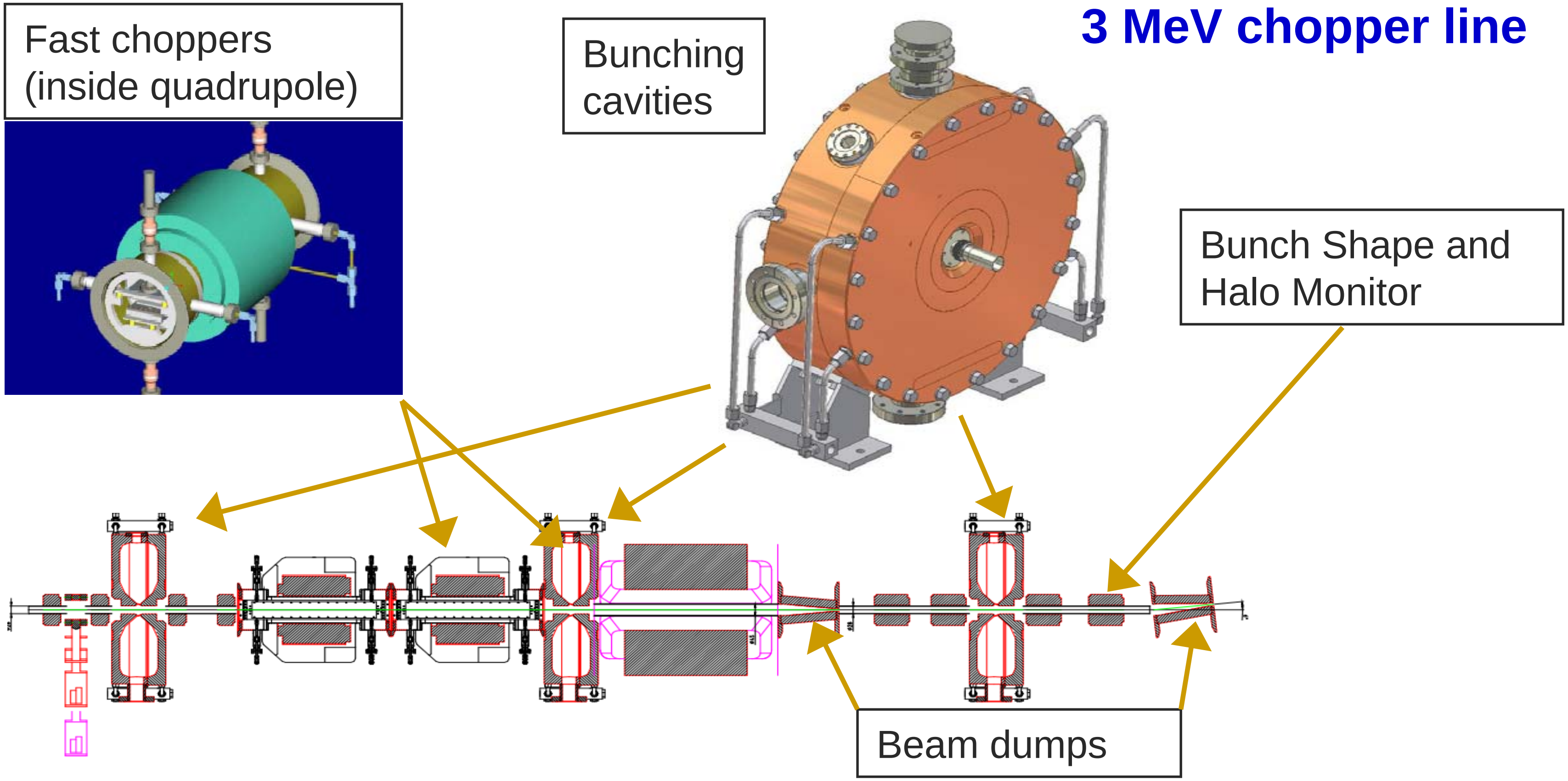
Progress towards Linac4 (2/4)

3 MeV test place



Progress towards Linac4 (3/4)

3 MeV chopper line



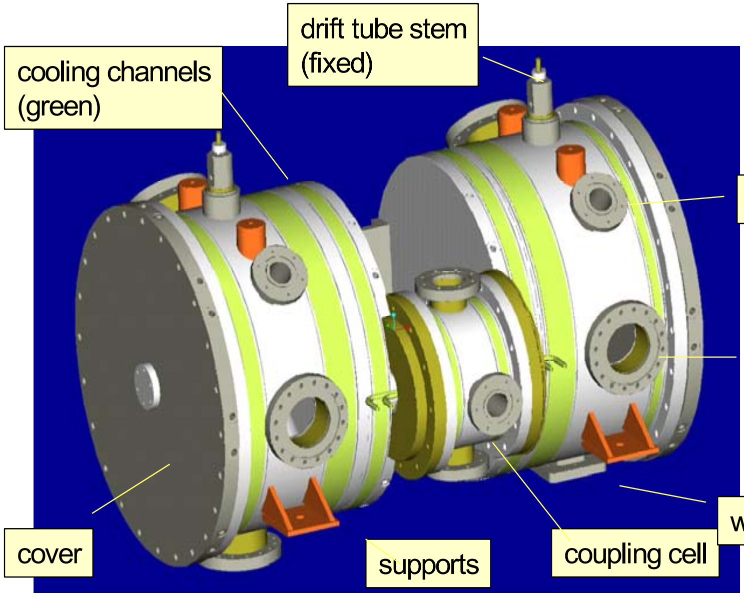
- 3.6 m long line, doing the beam chopping (minimization of longitudinal capture loss in the synchrotron) and the matching from RFQ to DTL.
- Beam dynamics studied; final prototypes of key equipments are in construction (chopper, buncher and BSHM)
- Quadrupoles and power supplies are recuperated from the CERN linacs

Progress towards Linac4 (4/4)

Development of Normal Conducting accelerating structures

3 – 40 MeV: **- DTL** (with CEA/IN2P3 and ITEP/VNIIEF): construction of a prototype Tank1 with dummy drift tubes + complete drift tube prototype (2006)
- or DTL-RFQ: high power prototype to be designed and built by IHEP/VNIIEF (2006)

40 – 90 MeV: **- CCDTL** full power one-cell prototype built at CERN (end 2003). Multi-cell prototype to be built at BINP/VNIITF (2006)



Diameter ~500 mm
Length ~ 800 mm

Material:
Cu-plated stainless steel

Assembling:
EB weldings, Helicoflex joints

machining and welding at CERN workshop finished (15.11.03)
to be tested with power in early summer 2004

90 – 160 MeV: - SCL: low power prototypes to be developed jointly by IN2P3 (Grenoble) and BINP/VNIITF

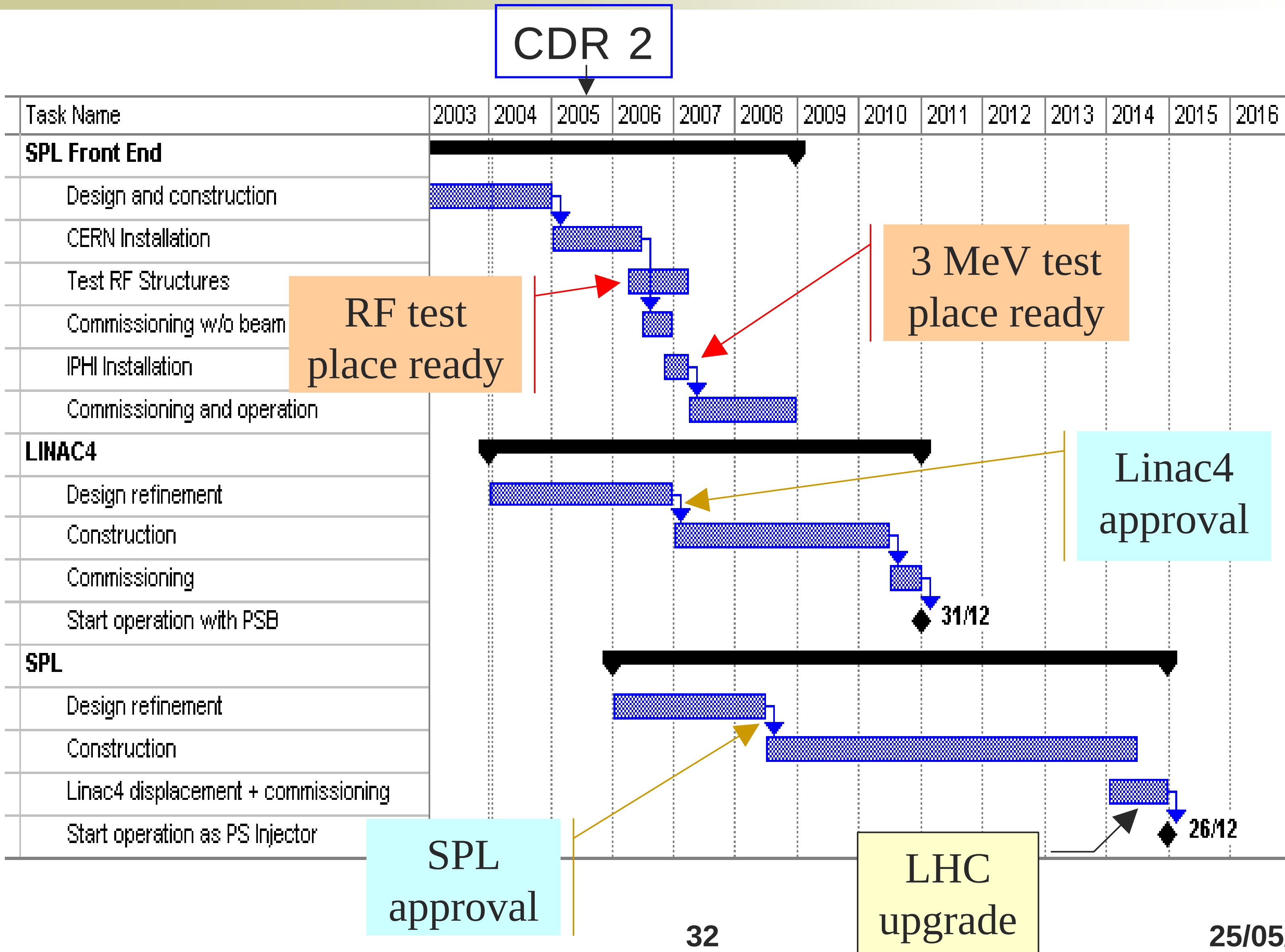
ROADMAP BEYOND LINAC 4…

“Show-starters”

- Competition with other projects will be tough: a successful project has to cover a broad range of experiments with a large number of users.
- A global economical optimum has to be found for the total cost “Accelerator(s) + Detectors”.
- Preparation of the design reports and construction will need much higher resources than today: resources for accelerator R & D have to increase over the years.
- Safety matters (radio-activity) must be addressed well in advance to optimize the design in that respect as well, and ease approval by authorities.

Possible planning

if the SPL is firmly supported…



FINAL WORD

Importance of this workshop

Issues debated at this workshop:

- potential for physics of a multi-MW proton source at a few GeV
- "optimum" beam characteristics to satisfy the broadest spectrum of experiments
- most valuable additions (staged realization ?)

will be essential to:

- refine the design of the accelerator(s) and compare alternative solutions
- orient the R & D and negotiate resources
- prepare information for the special SPC meeting next September

WE NEED YOUR HELP !
THANK YOU FOR BEING HERE !