The SPL at CERN

1. Introduction
2. Description
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3. Possible future stages
4. Goal and status of the SPL study

sLHC

Roa Garoby for the SPL team

18 June, 2009

1. Introduction

sLHC

Motivation for new injectors

1. Reliability ↑

The present accelerators are getting old (PS is 50 years old !) and they operate far beyond their initial design parameters

⇒ need for new accelerators designed for the needs of sLHC

2. Performance ↑

Brightness N/ε^* of the beam in LHC must be increased beyond the capability of the present injectors to allow for phase 2 of the LHC upgrade. [Excessive incoherent space charge tune spreads ΔQ_{SC} at injection in the PSB and PS].

$$\Delta Q_{SC} \propto \frac{N_b}{\varepsilon_{X,Y}} \cdot \frac{R}{\beta\gamma^2}$$

with N_b : number of protons/bunch

$\varepsilon_{X,Y}$: normalized transverse emittances

R : mean radius of the accelerator

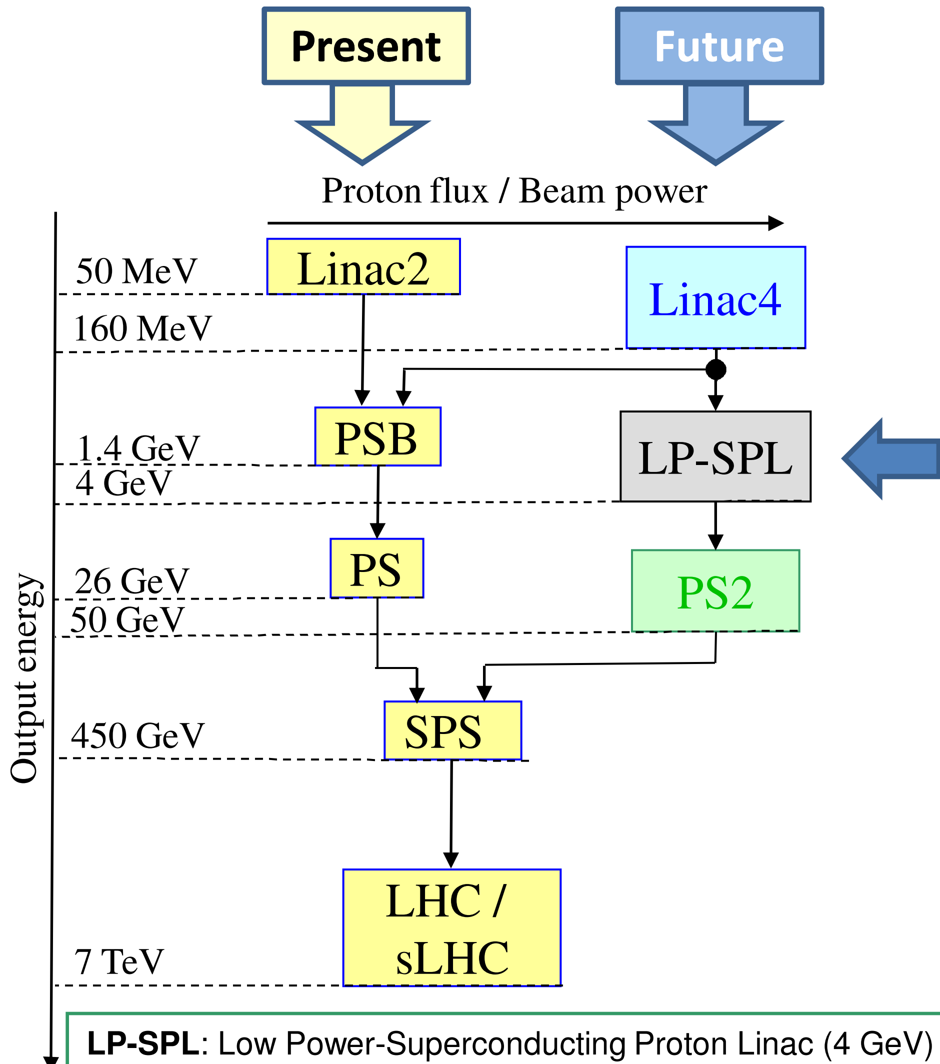
$\beta\gamma$: classical relativistic parameters

⇒ need to increase the injection energy in the synchrotrons

- **Increase injection energy in the PSB from 50 to 160 MeV kinetic**
- **Need for 4 GeV injection energy in PS2 (PS successor) to allow for 2.2 times the ultimate beam brightness in sLHC**
- **Increase injection energy in the SPS from 25 to 50 GeV kinetic (partly because of space charge, but mostly to inject further from transition energy and to displace TMCI threshold)**

Present and future accelerators

sLHC



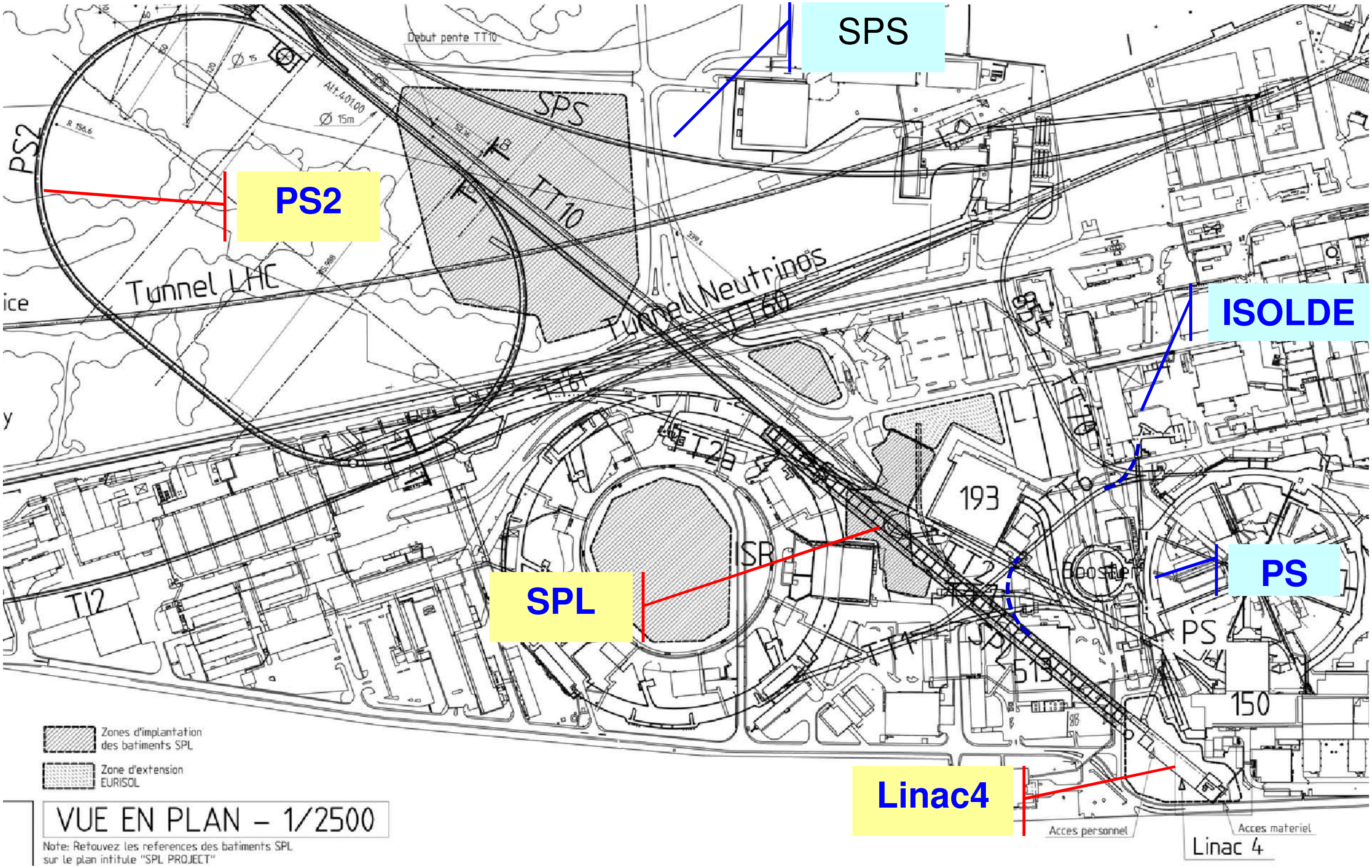
LP-SPL: Low Power-Superconducting Proton Linac (4 GeV)
PS2: High Energy PS (~ 5 to 50 GeV – 0.3 Hz)
sLHC: “Super-luminosity” LHC (up to 10^{35} $cm^{-2}s^{-1}$)

Main requirements of PS2 on its injector:

Requirement	Parameter	Value
2.2 x ultimate brightness with nominal emittances	Injection energy	4 GeV
	Nb. of protons / cycle for LHC (180 bunches)	6.7×10^{13}
Single pulse filling of SPS for fixed target physics	Nb. of protons / cycle for SPS fixed target	1.1×10^{14}
Provide all beam time structures for LHC	Bunch spacing	25/50/75 ns
	Number of bunches / missing bunches	1 - 168
Flexible control of emittance and intensity per bunch	$\varepsilon_{X,Y} / \varepsilon_L / N_b$	

sLHC

Site layout



2. Description

Stage 1: Linac4 - Main characteristics

sLHC

Ion species	H^-	
Output Energy	160	MeV
Bunch Frequency	352.2	MHz
Max. Rep. Rate	2	Hz
Max. Beam Pulse Length	1.2	ms
Max. Beam Duty Cycle	0.24	%
Chopper Beam-on Factor	65	%
Chopping scheme:		
222 transmitted /133 empty buckets		
Source current	80	mA
RFQ output current	70	mA
Linac pulse current	40	mA
N. particles per pulse	1.0	$\times 10^{14}$
Transverse emittance	0.4	π mm mrad

Max. rep. rate for accelerating structures: 50 Hz

H^- ⇒ charge exchange injection and painting in PSB

Higher injection energy on PSB (160/50 MeV, factor 2 in $\beta\gamma^2$) → same tune shift with twice the intensity.

Re-use of LEP RF components: klystrons, waveguides, circulators.

Chopping at low energy to reduce beam loss at PSB.

- Structures and klystrons dimensioned for 50 Hz
- Power supplies and electronics dimensioned for 2 Hz, 1.2 ms pulse.

Stage 1: Linac4 - Block diagram

sLHC

Linac4: 80 m, 18 klystrons

45keV	3MeV		3MeV	50MeV	94MeV	160MeV
H-	**RFQ**	**CHOPPER**	**DTL**	**CCDTL**	**PIMS**	

H-	RFQ	CHOPPER	DTL	CCDTL	PIMS
RF volume source (DESY) 45 kV Extrac.	Radio Frequency Quadrupole 3 m 1 Klystron 550 kW	Chopper & Bunchers 3.6 m 11 EMquad 3 cavities	Drift Tube Linac 18.7 m 3 tanks 3 klystrons 4.7 MW 111 PMQs	Cell-Coupled Drift Tube Linac 25 m 21 tanks 7 klystrons 7 MW 21 EMQuads	Pi-Mode Structure 22 m 12 tanks 8 klystrons ~12 MW 12 EMQuads

Ion current:
40 mA (avg.),
65 mA (peak)

RF accelerating structures: 4 types (RFQ, DTL, CCDTL, PIMS)
Frequency: 352.2 MHz
Duty cycle: 0.1% phase 1 (Linac4), 3-4% phase 2 (SPL), (design: 10%)

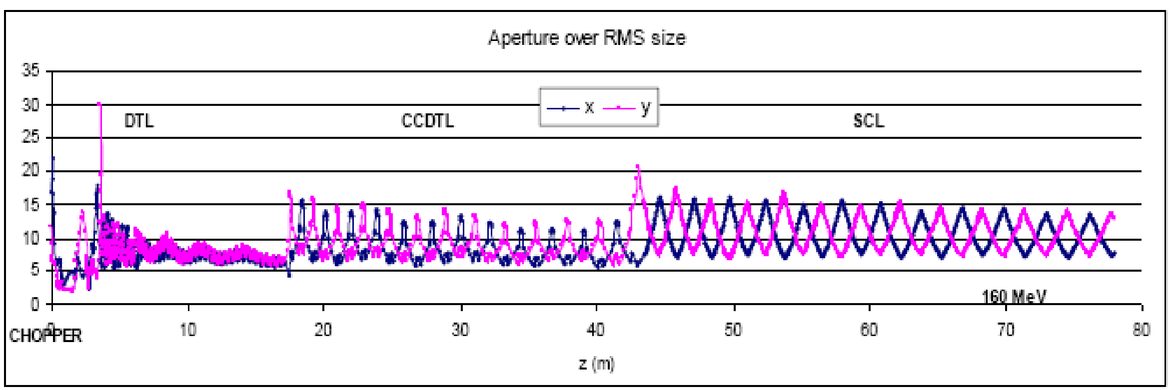
Stage 1: Linac4 - Beam dynamics

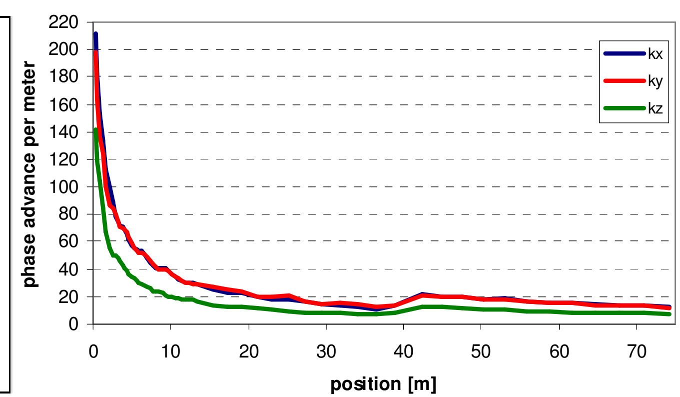
The Linac4 design (machine architecture, beam optics) allows for high beam power operation → it incorporates modern linac technologies developed for high-power projects (SNS, JPARC, ESS,…) – and has contributed to the development of some of these technologies ! – providing an operational margin for PSB and LP-SPL.

1. Beam optics design to minimize beam loss.
2. Chopping at low energy to reduce longitudinal capture losses in the synchrotron.
3. Charge exchange injection.
4. Remaining losses concentrated on defined spots (collimation)

Measures used for keeping beam loss < 1W/m (for hands-on maintenance) at high beam power:

1. Smooth phase advance transitions.
2. Operating point far from resonances.
3. Longitudinal to transverse phase advance ratio 0.5-08 (no emittance exchange).
4. Smooth variation of transverse and longitudinal phase advance.
5. Large apertures (> 7 rms beam size)





Stage 1 - Planning

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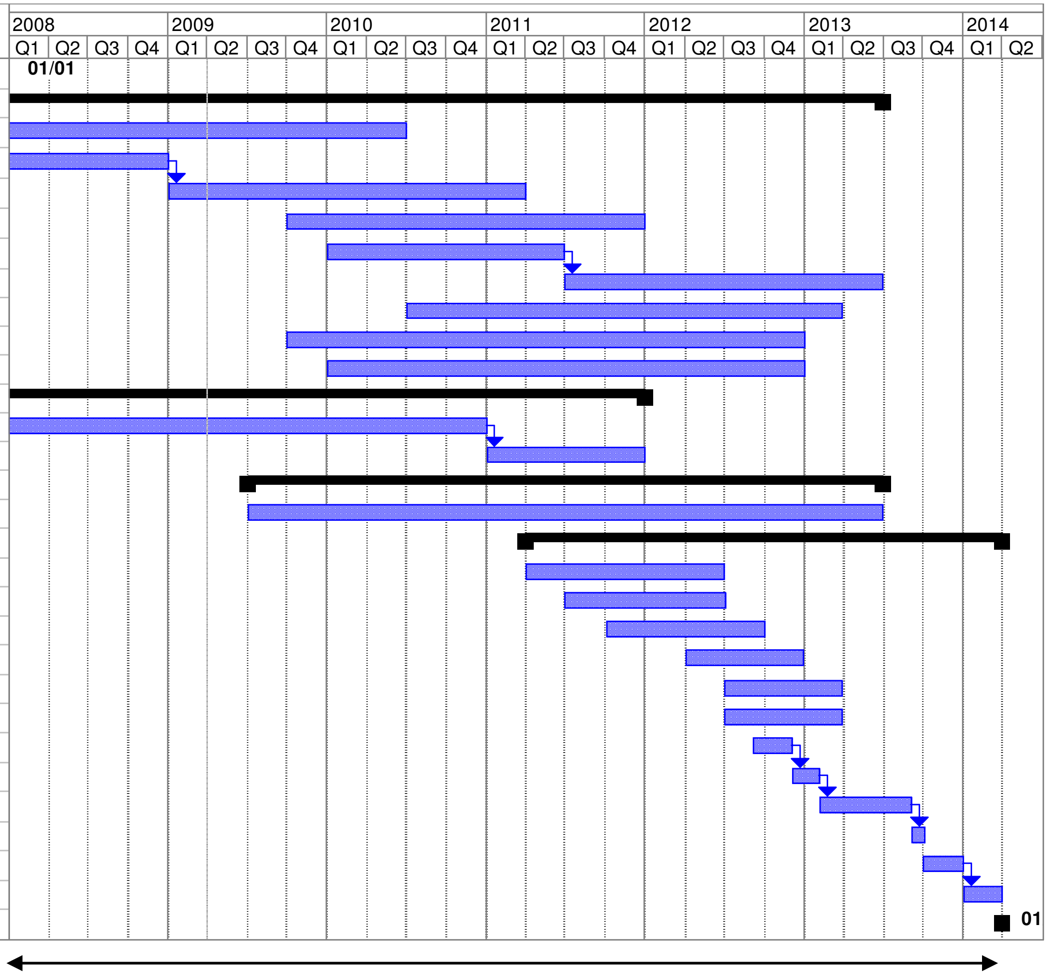
ID	Task Name
1	**Linac4 project start**
2	**Linac systems**
3	Source and LEBT construction, test
4	Drawings, material procurement
5	RFQ construction and commissioning
6	Accelerating structures construction
7	Klystron prototype production
8	Klystrons production
9	Transfer line construction and installation
10	Magnets construction
11	Power converters construction
12	**Building and infrastructure**
13	Building design and construction
14	Infrastructure installation
15	**PS Booster systems**
16	PSB injection elements construction
17	**Installation and commissioning**
18	Test stand operation
19	Cavities testing, conditioning
20	Cabling, waveguides installation
21	Accelerator installation
22	Klystrons, modulators installation
23	Hardware tests
24	Front-end commissioning
25	DTL1 commissioning
26	Linac accelerator commissioning
27	Transfer line commissioning
28	PSB modifications
29	PSB commissioning with Linac4
30	**PSB beam ready for PS**



project duration: 6 years

MILESTONES:

- ✓ Building delivery: December 2010
- ✓ Infrastructure installation: 2011
- ✓ Machine and equipment installation: 2012
- ✓ Linac commissioning: 2013
- ✓ PSB modifications: shut-down 2013/14.
- ✓ Beam from PSB: April 2014.

Stage 2: LP-SPL - Main characteristics

sLHC

Ion species	H^-	
Output Energy	4	GeV
Bunch Frequency	352.2	MHz
Max. Rep. Rate	2	Hz
Max. Beam Pulse Length	0.9	ms
Max. Beam Duty Cycle	0.2	%
Nominal chopping factor (Flexible chopping scheme)	65	%
Source current	40	mA
Linac pulse current	20	mA
Number of ions per pulse	1.1	$\times 10^{14}$
Transverse emittance	0.4	π mm mrad
Max. rep. rate for accelerating structures and klystrons:	50	Hz

Required for flexibility and low loss in PS2

Required by space charge tune spread at the specified beam brightness

Re-use of LEP RF components in Front-end (Linac4)

Required for flexibility and low loss in PS2 (linac4 chopper with new driver)

- Structures and klystrons dimensioned for 50 Hz
- Power supplies and electronics dimensioned for 2 Hz, 2 ms pulse.

Stage 2: LP-SPL - Main parameters

Frequency/temperature:

704 MHz and 2 K are confirmed,

Cavity gradient:

- 25 MV/m "on average" (= with a high yield) is very challenging and may be costly (in terms of reprocessing),
- 20 MV/m seems more achievable but will have an impact on linac length (or energy).

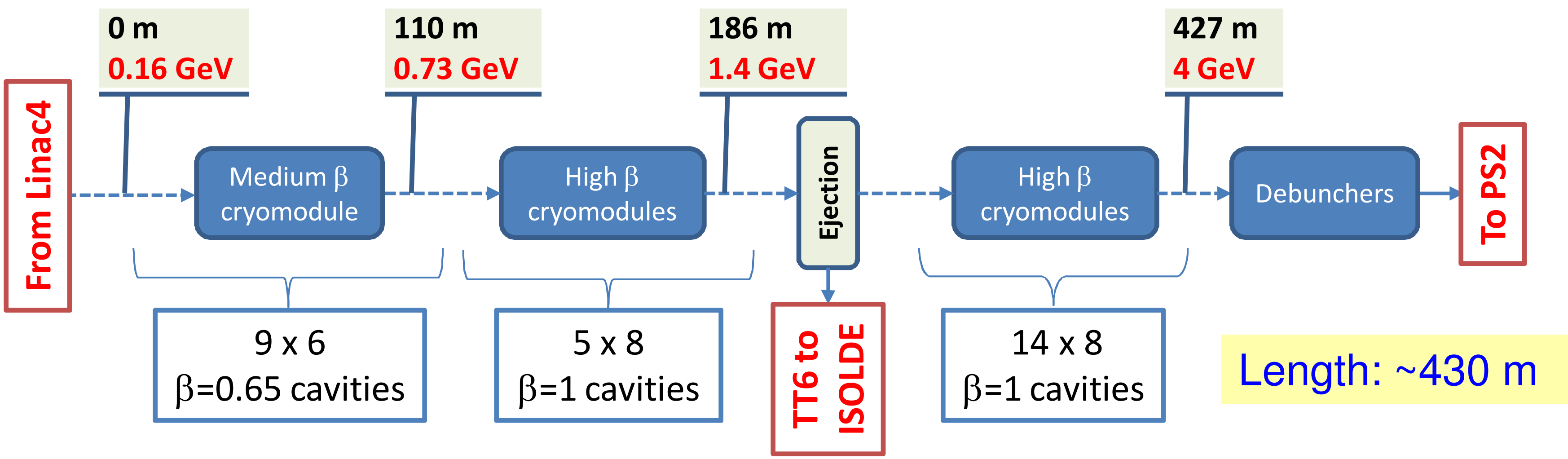
⇓

High-power RF cavity tests of fully equipped cryo-modules are mandatory for realistic SPL layout estimates!!

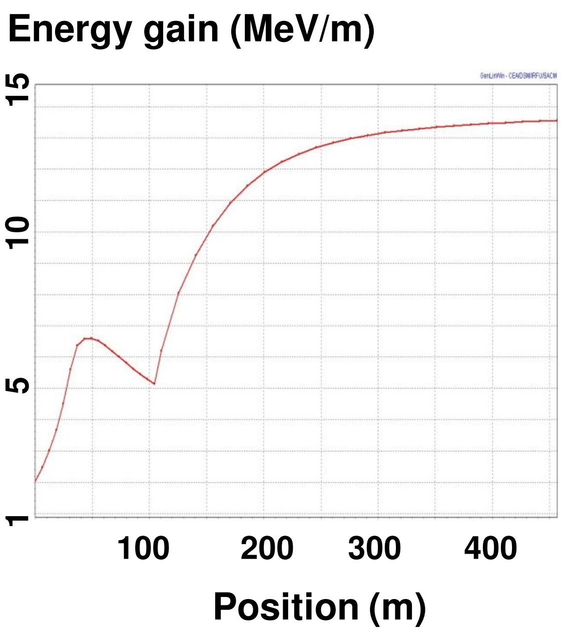
Ref.: Assessment of the basic Parameters of the CERN SPL, CERN-AB-2008-067-BI-RF, http://cdsweb.cern.ch/record/1136901/files/CERN-AB-2008-067.pdf

Stage 2: LP-SPL - Block diagram

SC-linac (160 MeV → 4 GeV) with ejection at intermediate energy

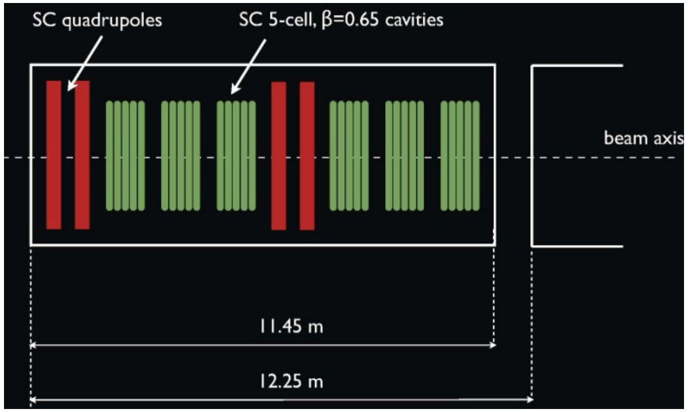


Stage 2: LP-SPL - Cryomodules



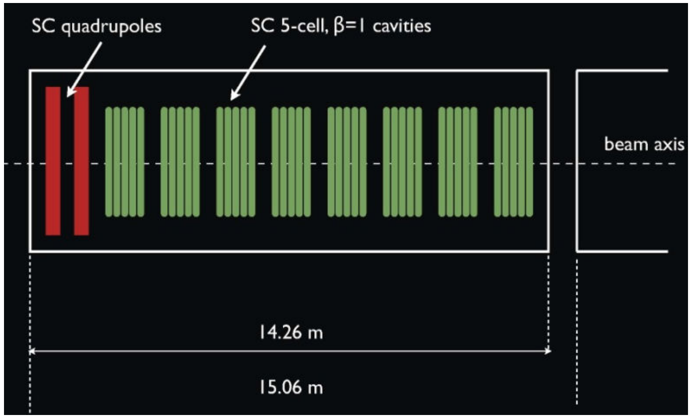
Medium β cryomodule

Energy range: 160 MeV – 732 MeV
5 cell cavities
Geometrical β: 0.65
Maximum energy gain: 19.4 MeV/m
54 cavities (9 cryomodules)
Length of medium β section: ~110.35 m



High β cryomodule

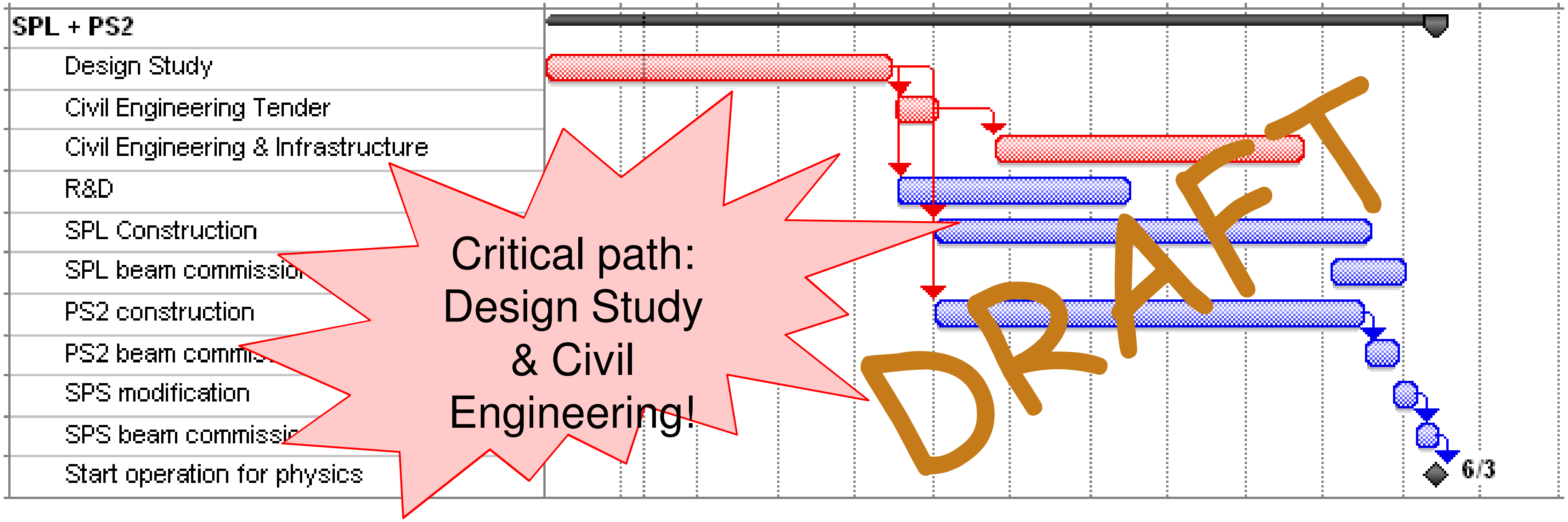
Energy range: 732 MeV – 4 GeV
5 cell cavities
Geometrical β: 1
Maximum energy gain: 25 MeV/m
152 cavities (19 cryomodules)
Length of medium β section: ~286.2 m



Implementation of the new injectors: **LP-SPL + PS2**

Construction of LP-SPL and PS2 will not interfere with the regular operation of Linac4 + PSB for physics.

Similarly, beam commissioning of LP-SPL and PS2 will take place without interference with physics.



First milestones

- Project proposal: 2011- 2012
- Project start: January 2013

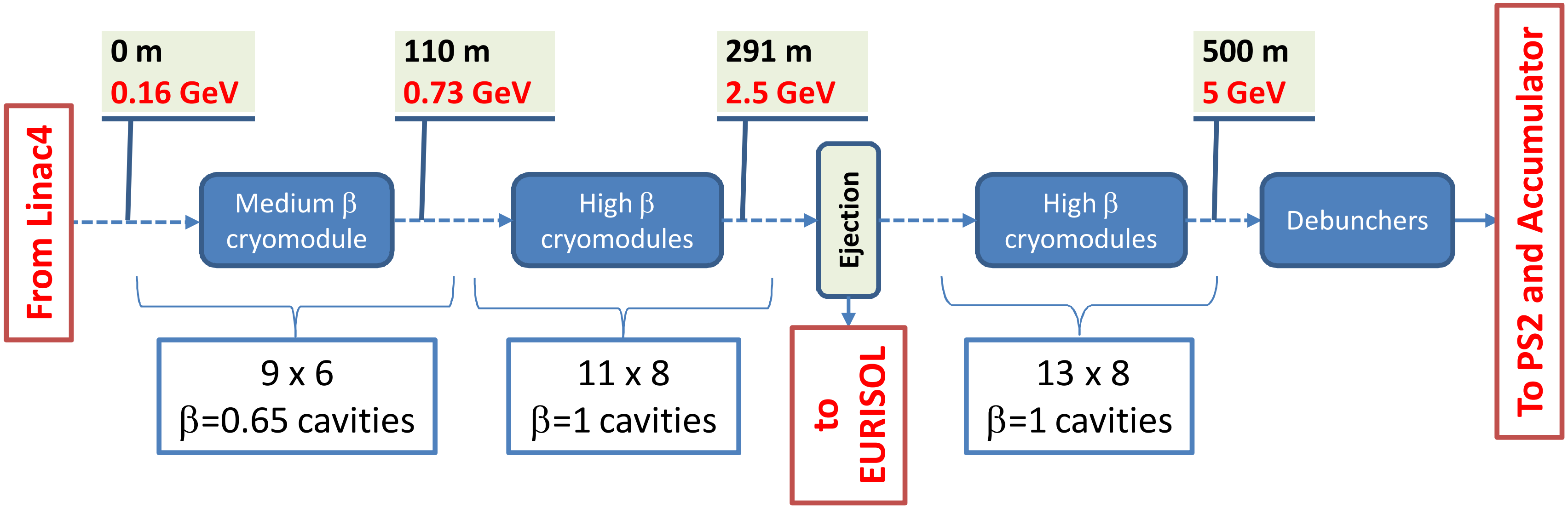
3. Possible future stages

High Power proton beams (HP-SPL) [1/2]

sLHC

- Replacement of klystron power supplies, upgraded infrastructure (cooling & electricity, etc.)
- Addition of 5 high β cryomodules to accelerate up to 5 GeV (π production for ν Factory))

SC-linac (160 MeV → 5 GeV) with ejection at intermediate energy



Length: ~500 m

High Power proton beams (HP-SPL) [2/2]

Beam characteristics of the main options

	Option 1	Option 2
Energy (GeV)	2.5 or 5	2.5 and 5
Beam power (MW)	2.25 MW (2.5 GeV) <u>or</u> 4.5 MW (5 GeV)	4 MW (2.5 GeV) <u>and</u> 4 MW (5 GeV)
Rep. frequency (Hz)	50	50
Protons/pulse (x 10^{14})	1.1	2 (2.5 GeV) + 1 (5 GeV)
Av. Pulse current (mA)	20	40
Pulse duration (ms)	0.9	0.8 (2.5 GeV) + 0.4 (5 GeV)

Faster rep. rate ⇒ new power supplies, more cooling etc.

2 × beam current ⇒ 2 × nb. of klystrons etc .

4. Goal and status of the SPL study

Goal of the SPL study (2008-2012)

from Note on 31/03/2009 (EDMS Id 993472)

The goal of the SPL study is to prepare for a start of construction of the low power SPL optimized for PS2 and LHC at the beginning of 2013.

For that purpose, a detailed Conceptual Design Report and a cost estimate will be published in May 2012. The cost of leaving the possibility of a later upgrade to 5 GeV and high beam power will also be quantified.

Organization

- **SPL (leader: R. Garoby) is part of the sLHC project (leader: L. Evans)**

  Administrative assistant: C. Noels (Cecile.Noels@cern.ch)

- **Organization of the SPL Study inside CERN**

Working Groups matched with the SPL collaboration (RF hardware, Cavities, Cryomodule, Beam dynamics)

	Coordinator	External partners
RF hardware (low & high power)	E. Ciapala	Cockcroft Institute
Cavities (structures & auxiliary equipment)	W. Weingarten	CEA-Saclay, CNRS-Orsay, TRIUMF, Stony Brook
Cryomodule (cryostat & cryogenics)	V. Parma	CEA-Saclay, CNRS-Orsay
Beam dynamics (beam parameters)	A. Lombardi	CEA-Saclay, TRIUMF, Soltan Institute, ESS
Architecture (layout & geometry, extraction, transfer)	F. Gerigk	
Surface treatment and vacuum	S. Calatroni	
Integration* (interface with Civil Engineering and all services)	S. Weisz	
Safety* (safety file, INB procedures)	???	
Linac4	M. Vretenar	

* For all accelerators

sLHC

Documentation and information

Access to documentation and meetings

- sLHC Web site (work in progress…)
- New series for sLHC reports and project notes on the CERN Document Server
- Structured storage for all SPL documentation in EDMS
- Structured filing of all SPL meetings in Indico

Work progress (1/3)

Progress in 2008:

- Choice of β=1 for the high energy cavities (F. Gerigk et al., "Choice of the optimum beta for the SPL SC cavities")
- "Healthy" debate on the risks of HOMs… (J. Tuckmantel, "HOM dampers or not in SC RF proton linacs", CERN BE-Note-2009-009)

  to be concluded during a dedicated workshop on June 25-26 at CERN [http://indico.cern.ch/conferenceDisplay.py?confId=57247]
- Collection of information/discussion during an ESS-Bilbao workshop

  on March 16-18 [http://workshop2009.essbilbao.com/cas/index.aspx]
- Decision to pass one waveguide per cavity between technical gallery and accelerator tunnel
- Reduction of the beam pulse to match the updated needs of PS2 (0.9 ms instead of 1.2 ms)
- Analysis of beam stability in the accumulator of the SPL-based proton driver (talk at NuFact09)
- Refinement of beam parameters for RIB facility (ies).

Work progress (2/3)

sLHC

Main technical milestones in 2009:

- **Accelerator layout with intermediate energy ejections: 05/2009**
- **HOM damper specifications (?): 06/2009**
- **[dedicated workshop on June 25-26, 2009 at CERN (http://indico.cern.ch/conferenceDisplay.py?confId=57247)]**
- **Location of beam instrumentation: 06/2009**
- **Decision on high power RF source (=> modulator specifications): 08/2009**
- **Orientation of RF coupler: 09/2009**
- **Coordination of sc cavities development: 09/2009**
  [dedicated meeting in September 2009 at CERN – before SRF09]
- **Decision on supporting of cryomodules: 10/2009**
- **Decision on sectorization of cryogenics: 10/2009**
  [dedicated workshop in September 2009 at CERN]
- **Collection of all parameters for dimensioning tunnels and buildings: 12/2009**

Work progress (3/3)

Goals in 2010 and 2011:

- Construction and test of prototypes [cavities and auxiliary equipment (couplers, dampers, tuners), Klystron modulator, …]
- Order /installation/commissioning of high power RF amplifier
- CE preliminary study and geological investigations
- Impact study
- Upgrade of the SM18 test place [cryogenics and RF]
- Design and construction of prototype cryomodule
- Report writing

Goals in 2012:

- Final edition of report
- Preparation of CE tender documentation
- Impact study report
- Cost estimate
- Equipment and test in SM18 of the fully equipped cryomodule
- Design and preparation of orders for pre-series equipment

SPL collaboration (1/4)

Main support inside EU-FP7

Instrument	Subject	Partners	Time period
CNI-PP « SLHC »	R & D towards the SPL H^- source	CERN, DESY, STFC-DL	April 2008 – March 2011
	Stabilization of RF field in a pulsed superconducting proton linac	CEA-Saclay, CERN, INFN	
IA « EuCARD »	Development of SC cavities for a pulsed superconducting proton linac	CEA-Saclay, CERN, CNRS	April 2009 – March 2013

SPL collaboration (2/4)

sLHC

Other partners

Status	Partner	Nature	Subjects
Signed in 2008	SNS Oak Ridge	Balanced (SNS upgrade / SPL)	• Laser stripping for charge exchange injection • High power modulators for klystrons
	Cockcroft Institute	UK participation to the sLHC	• Beam dynamics • Development of high power RF components
	ESS	Balanced : in-kind contributions against CERN know-how	• RF design • Beam dynamics • Hardware for Linac4 • High power modulators for klystrons?
	CEA + CNRS	French in-kind contribution	• Cryomodule design • Components and tools for the SPL cryomodule

SPL collaboration (3/4)

sLHC

Other partners

Status	Partner	Nature	Subjects
Being finalized	TRIUMF	Canadian contribution to the sLHC	• Development of SRF β=0.65 cavities • Beam dynamics
	US-LARP	US contribution to sLHC	• Laser Profile Monitors (Linac4)
	Stony Brook / BNL	US support to SBIRs in SRF technology / US contribution to SLHC	• Development of SRF β=1 cavity
	Soltan Institute	Manpower against training	• Beam dynamics • RF
Declared interest	FNAL	Balanced (Project-X / SPL)	• High power RF components • Chopper driver • Charge exchange injection
	DAE (India)	NAT agreement	• ?
	IHEP (Beijing)		• ?
	ASTEC-Royal Holloway	UK participation to the sLHC	• ?

SPL collaboration (4/4)

sLHC

ACTIVITY OF THE COLLABORATION:

Meetings:

- ***1st meeting of the SPL Collaboration on December 11-12, 2008 at CERN***
  http://indico.cern.ch/conferenceDisplay.py?confId=44821
- ***2nd meeting of the SPL Collaboration on May8-9, 2009 in Vancouver***
  http://indico.cern.ch/conferenceDisplay.py?confId=56127
- ***3rd meeting of the SPL Collaboration in November, 2009 at CERN***

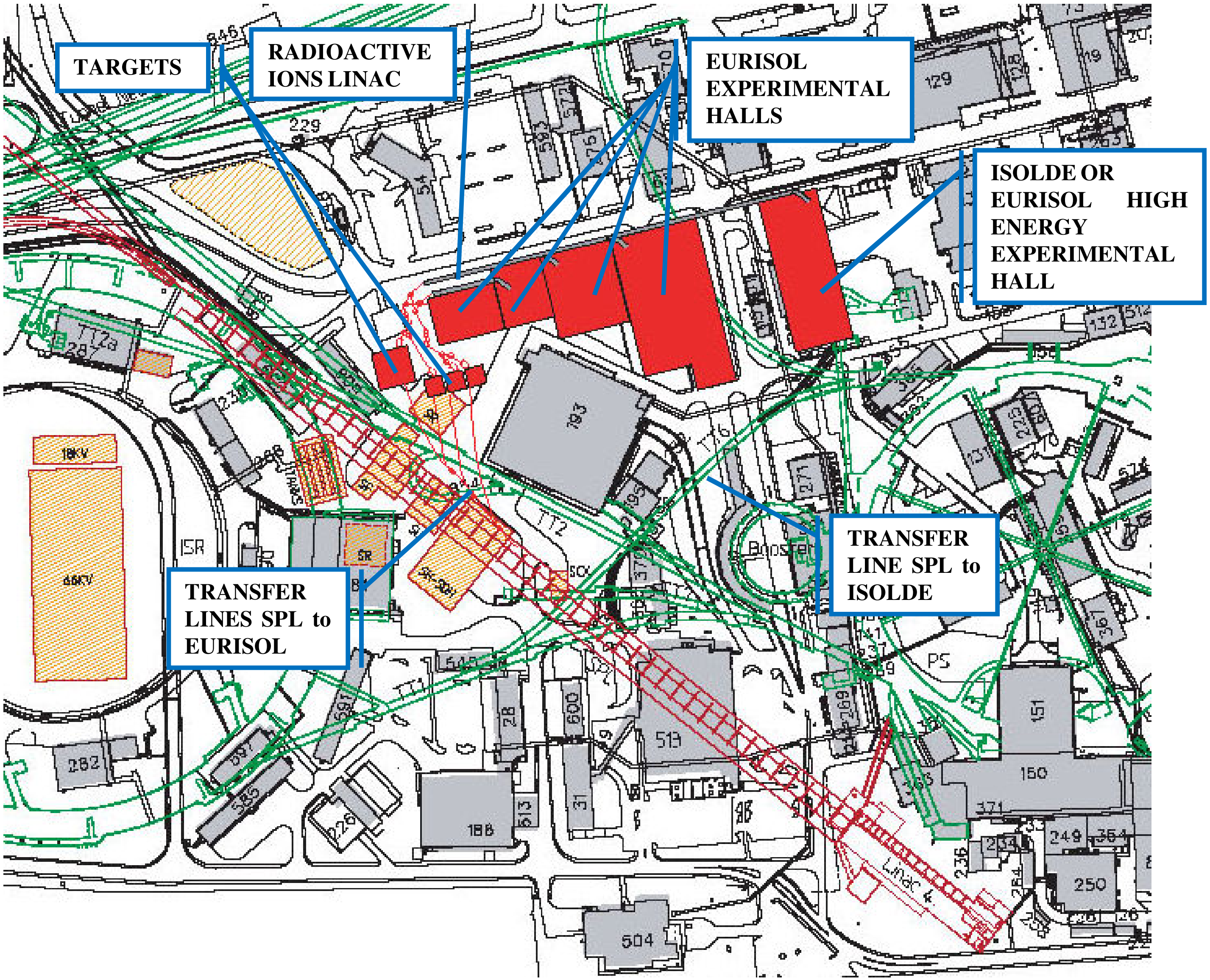
MoU:

- draft version circulating inside CERN. Soon to be submitted to the partners.
- will create a Collaboration Board.

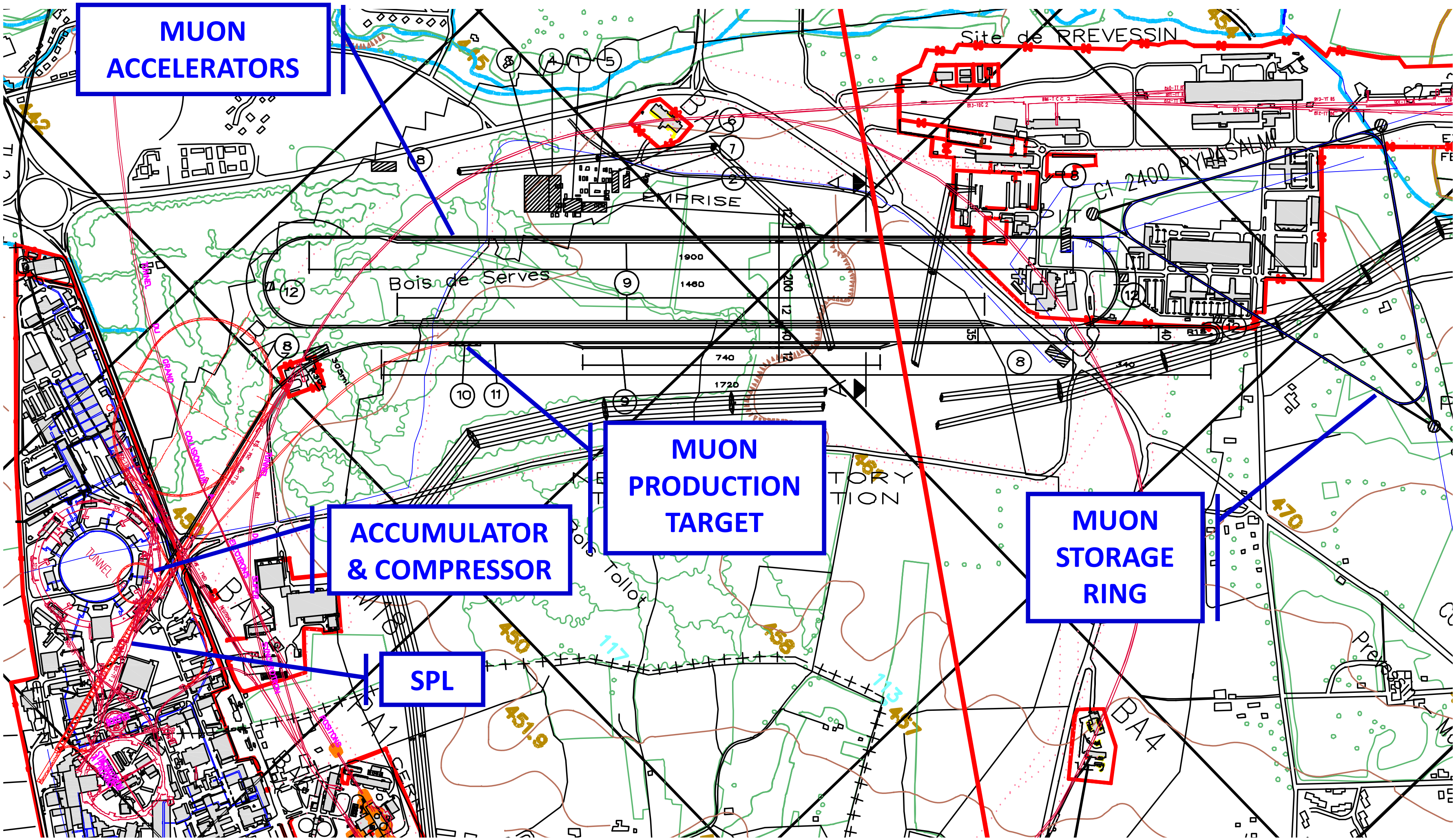
THANK YOU FOR YOUR ATTENTION!

High power proton applications

ISOLDE & EURISOL



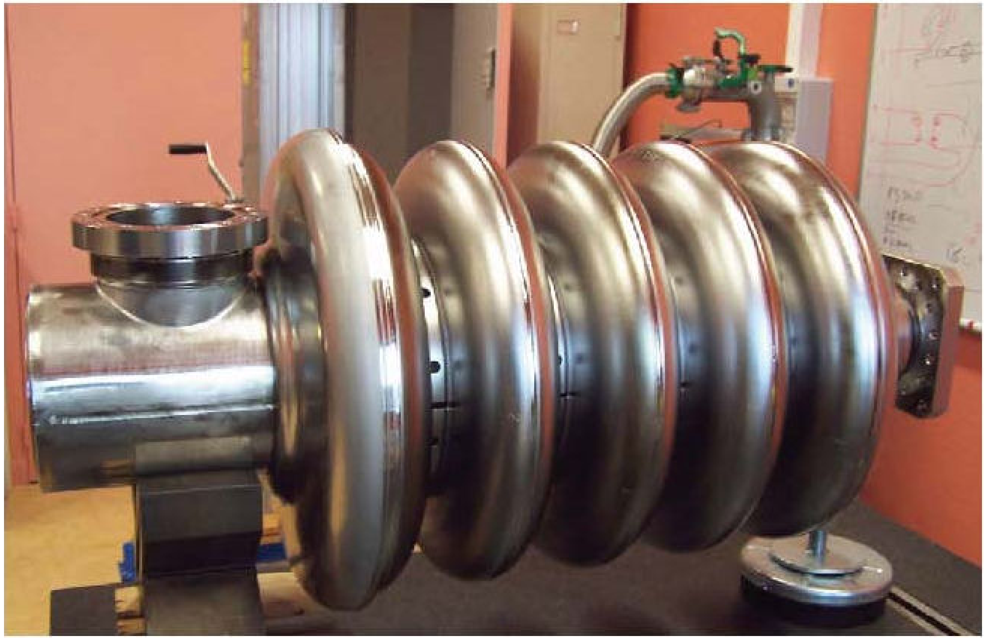
Neutrino Factory



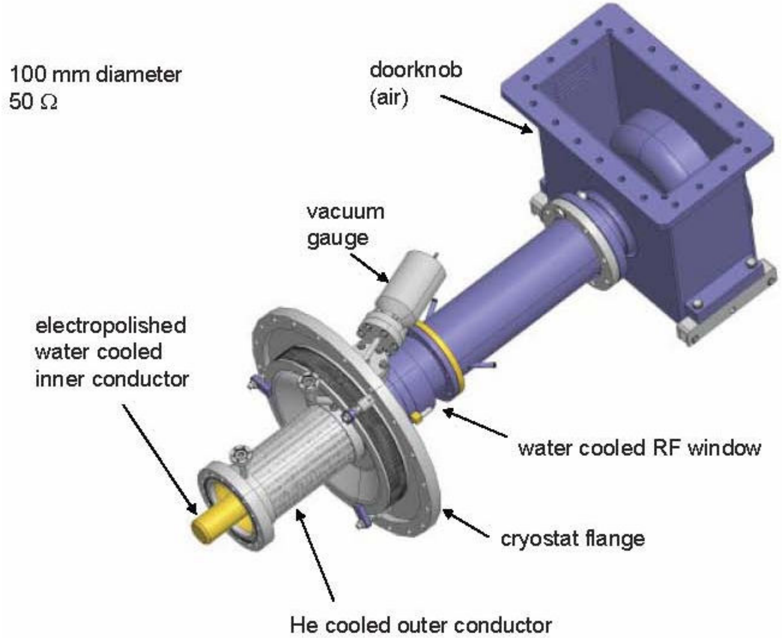
Spare slides

Technology

Elliptical 5 cell bulk Niobium cavities
(e.g.: β=0.47)



Auxiliary equipment
(e.g.: 1 MW RF coupler)



from G. Devanz – HIPPI meeting Nov. 2007)

Parameters: RF frequency [1/3]

Frequency	704 MHz	1408 MHz
Length (5 GeV)	472 m	+12%
$N_{cavities}$	246	+15%
$N_{\beta\text{-families}}$	2	3
ε-growth (x/y/z)	5.6/8.2/6.8	6.3/7.8/12.1
Longitudinal beam loss	none in simulations	lossy runs for realistic RF gradient/phase variations
BBU (HOM)	$I_{BBU,704}$	1/(8..128)
Trapped modes	normal risk	2..4 higher risk
RF power density limit (RF distribution)	ok	problematic
Klystrons	comfortable: MBK	difficult
Overall power consumption (RF+cryo, nom. SPL)	28 MW	up to -30%
Power converter	more bulky	saves tunnel space
Synergy with ESS	yes	no

Parameters: Cooling temperature [2/3]

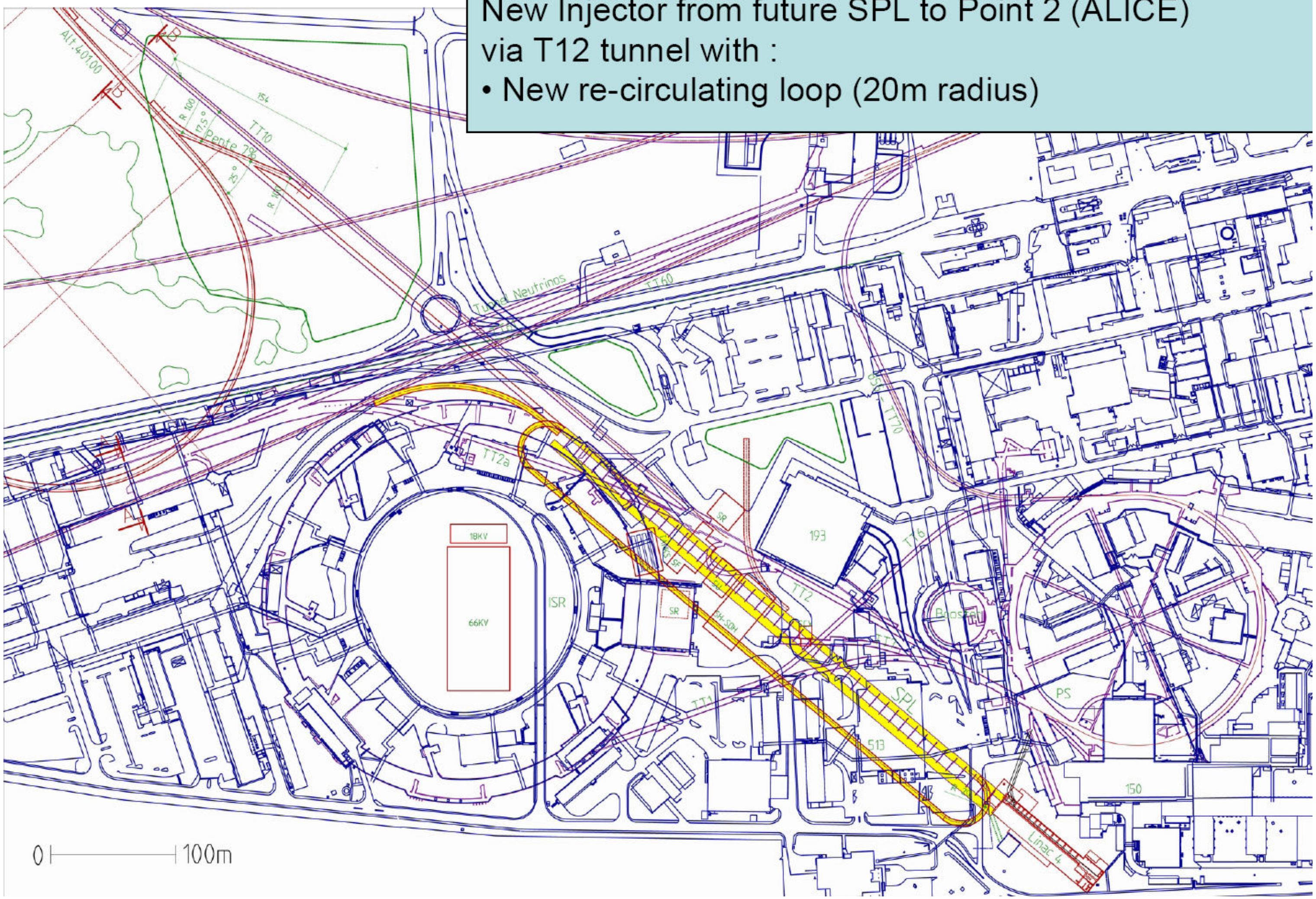
@ 704 MHz	T [K]	Eq. capacity @ 4.5 K [kW]	Electrical power [MW]
HP-SPL, 2% beam d.c. (4% cryo d.c.)	2	19.4	4.48
HP-SPL, 2% beam d.c. (4% cryo d.c.)	4.5	104	26.0
LP-SPL, 0.24% beam d.c. (0.32% cryo d.c.)	2	6.1	1.5
LP-SPL, 0.24% beam d.c. (0.32% cryo d.c.)	4.5	11	2.75

+ not clear that 25 MV/m can be achieved at 4.5 K!

e+/e- acceleration

LHeC: 20 GeV e+/e- from the SPL (5-pass acceleration in the β=1 section) as a pre-injector for a lepton ring in the LHC tunnel (Ring/Ring option)

New Injector from future SPL to Point 2 (ALICE)
via T12 tunnel with :
- New re-circulating loop (20m radius)



Objectives

RF hardware (low level & high power)	Define RF system Demonstrate feasibility
Cavities (structures & auxiliary equipment)	Demonstrate feasibility Decide on design of cavities, tuner, couplers and integration in cryostat
Cryomodule (cryostat & cryogenics)	Design cryomodule and integration, + tools Assemble prototype
Beam dynamics (beam parameters)	Lattice and longitudinal design Specs. of beam characteristics (losses) Design collimation scheme(s)
Architecture (layout & geometry, extraction, transfer)	SPL geometry and layout Geometry and layout of extraction and transfer Design and layout of collimators and dumps
Surface treatment and vacuum	Develop treatment for SPL sc cavities at CERN Contribute to the design of the cryomodule (vacuum issues)
Integration* (interface with Civil Engineering and all services)	Specs. of services (cooling, vent. , etc.) Drawings for Civil Engineering and equipment installation Environmental impact
Safety* (safety file, INB procedures)	Safety file INB procedure
Linac4	Compatibility with SPL (all versions…)