European Organization for Nuclear Research

Organisation Européenne pour la Recherche Nucléaire

STATUS OF THE SPL

R. Garoby – 24/11/2008

OUTLINE

1. Reminder:
   - Motivation for renovating the injectors
   - Description
   - Stages of implementation
2. SPL Design
3. Work Plan
4. Collaborations
5. Perspectives with low emittances

1. REMINDER: Motivation

1. Lack of reliability:

   Ageing accelerators (PS is 48 years old !) operating far beyond initial parameters

$\Rightarrow$ need for new accelerators designed for the needs of SLHC

2. Main performance limitation:

Excessive incoherent space charge tune spreads ΔQ_{SC} at injection in the PSB (50 MeV) and PS (1.4 GeV) because of the high required beam brightness N/ε^*.

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

with N_b : number of protons/bunch

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

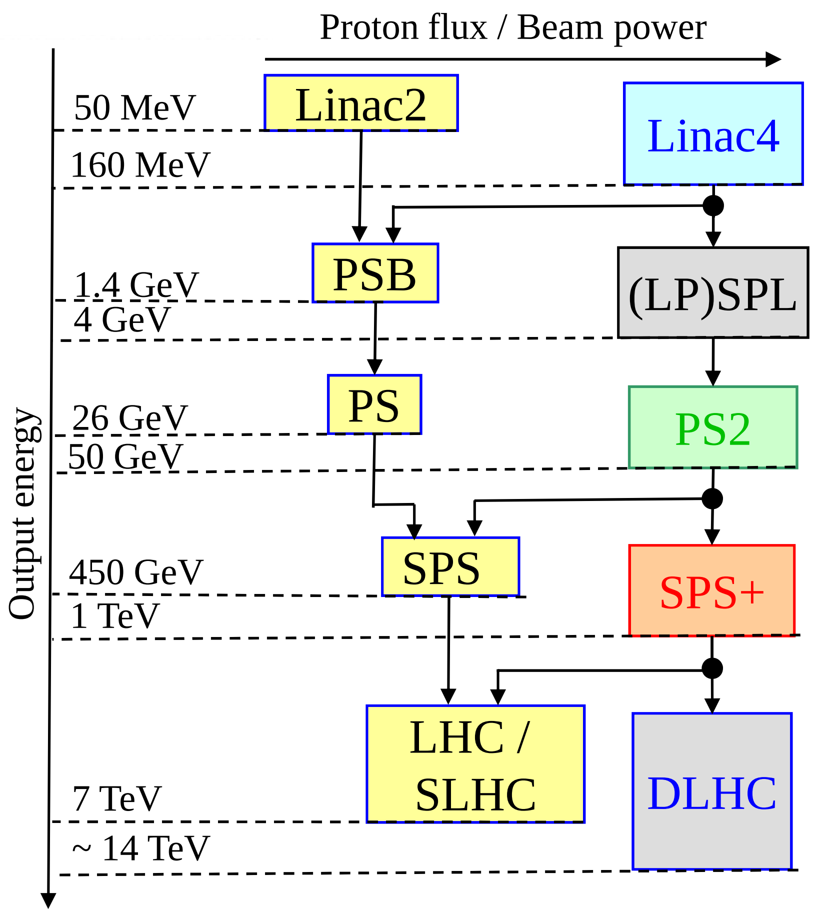
R : mean radius of the accelerator

$\beta\gamma$: classical relativistic parameters

$\Rightarrow$ need to increase the injection energy in the synchrotrons

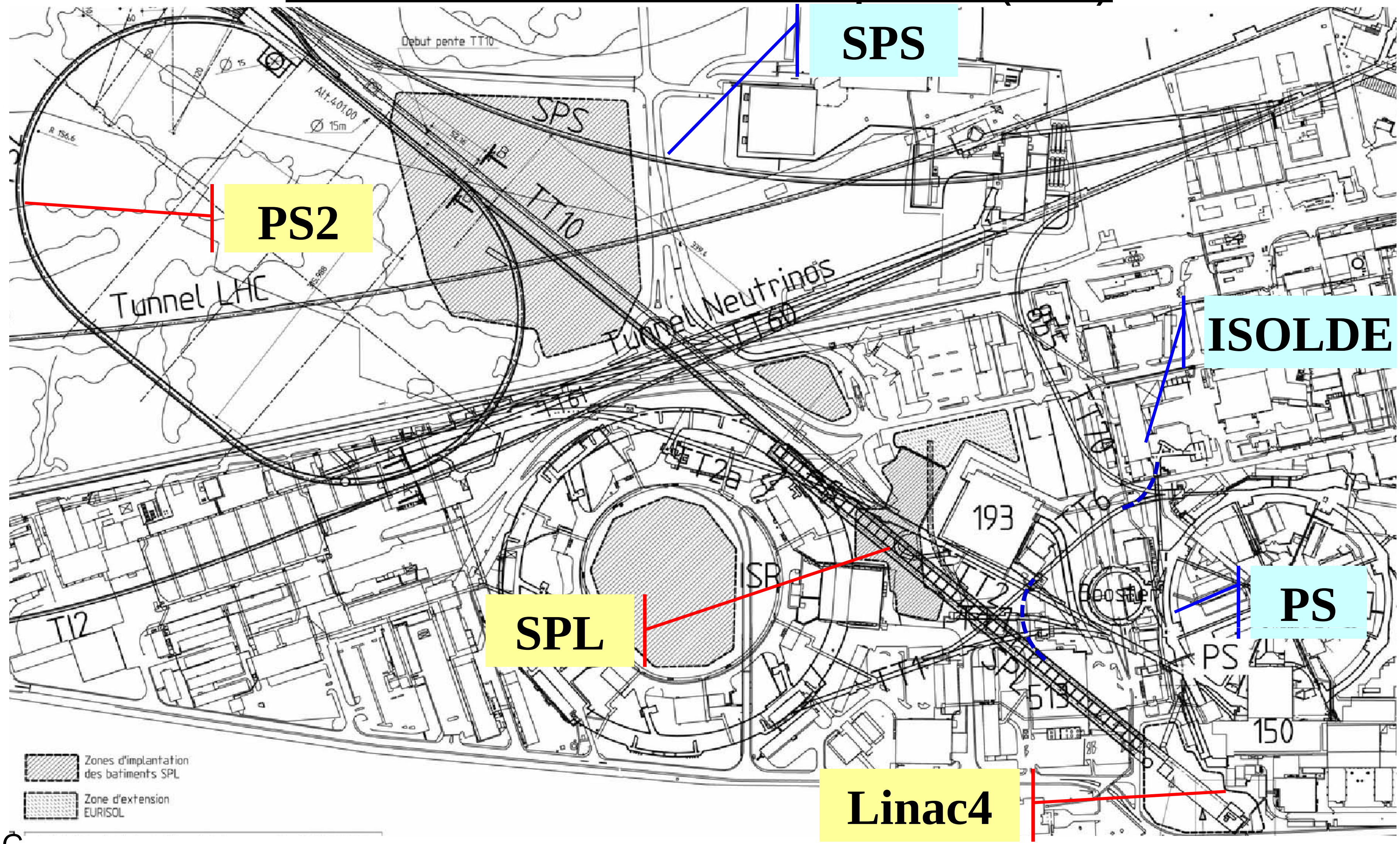
- Increase injection energy in the PSB from 50 to 160 MeV kinetic
- Increase injection energy in the PSB from 25 to 50 GeV kinetic
- Design the PS successor (PS2) with an acceptable space charge effect for the maximum beam envisaged for SLHC: => injection energy of 4 GeV

1. REMINDER: Description (1/2)



(LP)SPL: (Low Power) Superconducting Proton Linac (4-5 GeV)
PS2: High Energy PS (~ 5 to 50 GeV – 0.3 Hz)
SPS+: Superconducting SPS (50 to1000 GeV)
SLHC: "Superluminosity" LHC (up to 10^{35} $cm^{-2}s^{-1}$)
DLHC: "Double energy" LHC (1 to ~14 TeV)

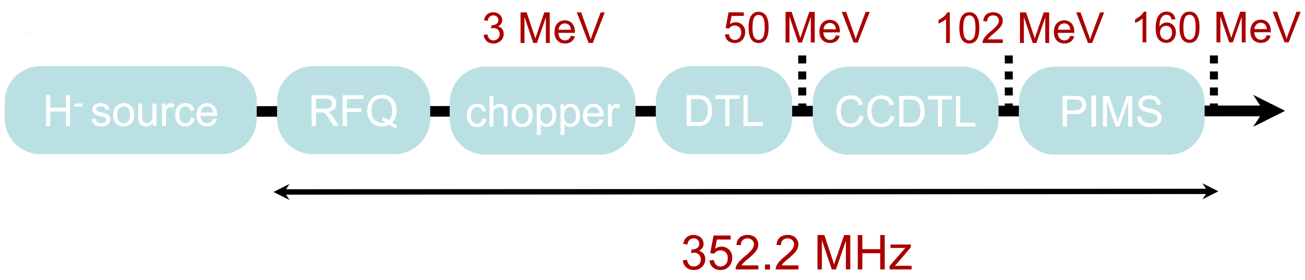
1. REMINDER: Description (2/2)



1. REMINDER: Stage 1 (1/2)

LINAC4

Layout

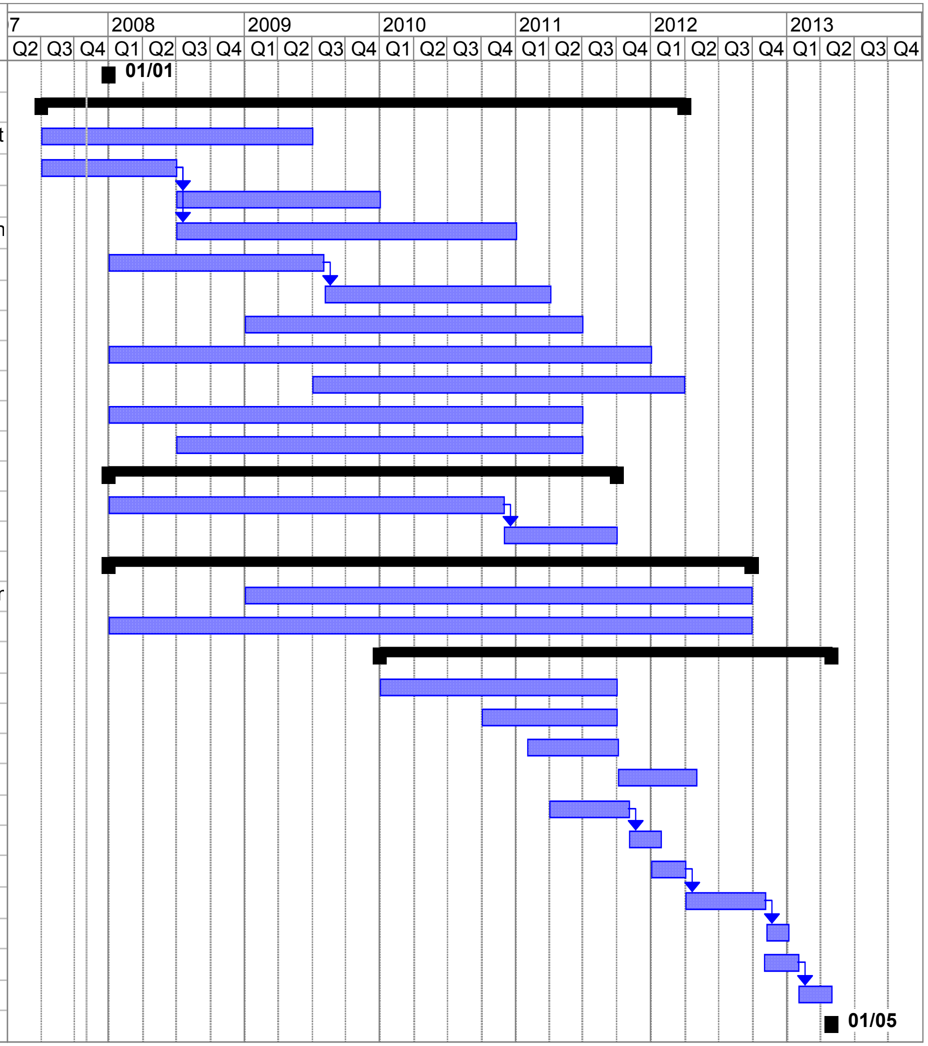


Beam characteristics

Ion species	**H^-**
Output kinetic energy	**160 MeV**
Bunch frequency	**352.2 MHz**
Max. repetition rate	**1.1 (2) Hz**
Beam pulse duration	**0.4 (1.2) ms**
Chopping factor (beam on)	**62%**
Source current	**80 mA**
RFQ output current	**70 mA**
Linac current	**64 mA**
Average current during beam pulse	**40 mA**
Beam power	**5.1 kW**
Particles / pulse	**$1.0\ 10^{14}$**

1. REMINDER: Stage 1 (2/2)

WBS	Task Name
	Linac4 project start
2	**Linac systems**
2.1	Source and LEBT construction, test
	Drawings, material procurement
2.2	RFQ construction, test
2.4	Accelerating structures construction
	Klystron prototyping
2.6.	Klystrons construction
2.6.	LLRF construction
2.7	Beam Instrumentation construction
2.8	Transfer line construction
2.9	Magnets construction
2.10	Power converters construction
5	**Building and infrastructure**
5.1	Building design and construction
5.2,3,	Infrastructure installation
3	**PS Booster systems**
3.1	PSB injection elements construction
3.2	PSB beam dynamics analysis
4	**Installation and commissioning**
4.1	Test stand operation (3 + 10 MeV)
4.2	Cavities testing, conditioning
	Cabling, waveguides installation
	Accelerator installation
	Klystrons, modulators installation
	Hardware tests
	Front-end commissioning
4.5	Linac accelerator commissioning
	Transfer line commissioning
	PSB modifications
4.6	PSB commissioning with Linac4
	Start physics run with Linac4

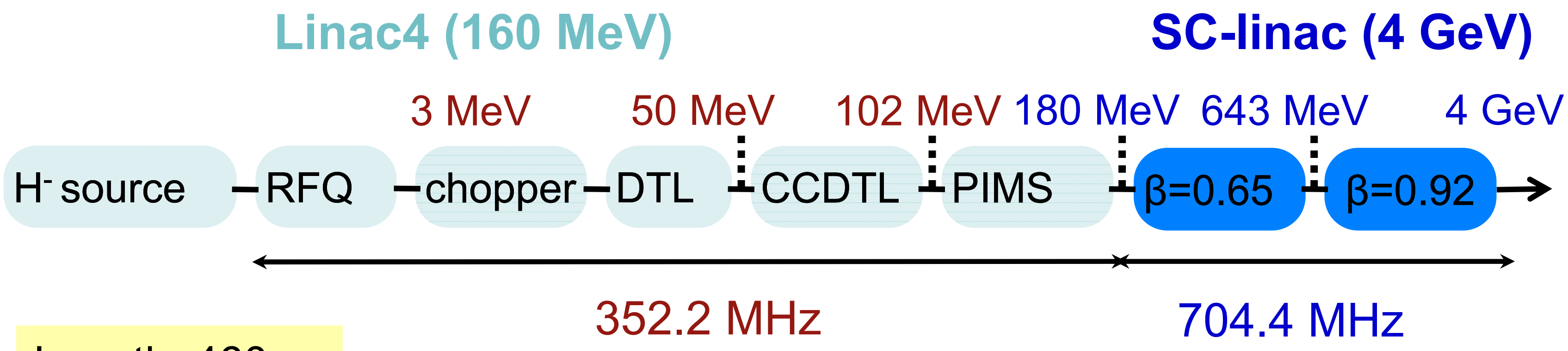


Milestones

- End CE works: December 2010
- Installation: 2011
- Linac commissioning: 2012
- Modifications PSB: shut-down 2012/13 (6 months)
- **Beam from PSB: 1rst of May 2013**

1. REMINDER: Stage 2 (1/3)

LP-SPL



Length: 460 m

LP-SPL beam characteristics

Kinetic energy (GeV)	**4**
Beam power at 4 GeV (MW)	**0.16**
Rep. period (s)	**0.6**
Protons/pulse (x 10^{14})	**1.5**
Average pulse current (mA)	**20**
Pulse duration (ms)	**1.2**

R.G.
24/11/2008

1. REMINDER: Stage 2 (2/3)

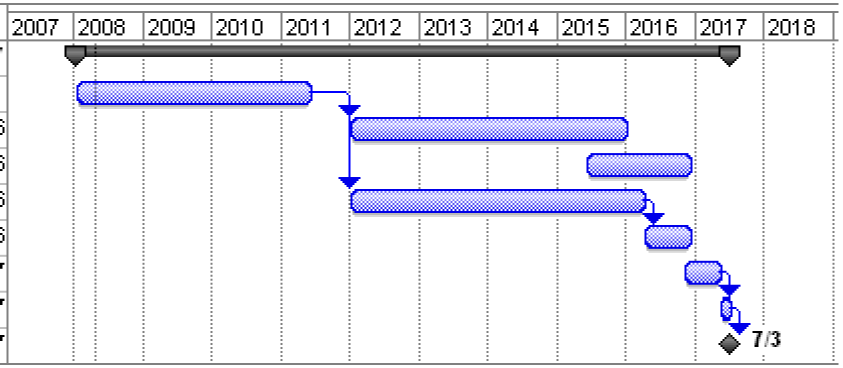
PS2 main characteristics compared to the present PS

	PS2	PS
Injection energy kinetic (GeV)	4.0	1.4
Extraction energy kinetic (GeV)	~ 50	13/25
Circumference (m)	1346	628
Maximum intensity LHC (25ns) (p/b)	4.0×10^{11}	$\sim 1.7 \times 10^{11}$
Maximum intensity for fixed target physics (p/p)	1.2×10^{14}	3.3×10^{13}
Maximum energy per beam pulse (kJ)	1000	70
Max ramp rate (T/s)	1.5	2.2
Cycle time at 50 GeV (s)	2.4	1.2/2.4
Max. effective beam power (kW)	400	60

1. REMINDER: Stage 2 (3/3)

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.

ID	Task Name	Start	Finish
1	**SPL + PS2**	**Mon 1/7/08**	**Mon 7/3/17**
2	Design	Mon 1/7/08	Wed 6/1/11
3	SPL Construction	Mon 1/2/12	Fri 1/1/16
4	SPL beam commissioning	Mon 6/1/15	Fri 12/2/16
5	PS2 construction	Mon 1/2/12	Fri 4/1/16
6	PS2 beam commissioning	Mon 4/4/16	Fri 12/2/16
7	SPS modification	Fri 11/4/16	Fri 5/5/17
8	SPS beam commissioning	Mon 5/8/17	Fri 6/30/17
9	Start operation for physics	Mon 7/3/17	Mon 7/3/17

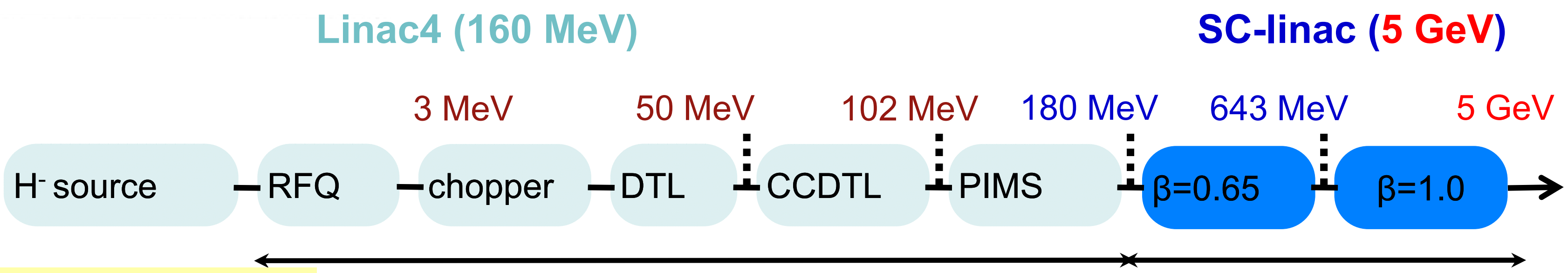


Milestones

- Project proposal: June 2011
- Project start: January 2012
- LP-SPL commissioning: mid-2015
- PS2 commissioning: mid-2016
- SPS commissioning: May 2017
- **Beam for physics: July 2017**

1. REMINDER: Stage 3 (1/2)

HP-SPL



Length: 460 m

352.2 MHz　　704.4 MHz

HP-SPL beam characteristics

	Option 1	Option 2
Energy (GeV)	**2.5 or 5**	**2.5 and 5**
Beam power (MW)	**3 MW (2.5 GeV) or 6 MW (5 GeV)**	**4 MW (2.5 GeV) and 4 MW (5 GeV)**
Rep. frequency (Hz)	**50**	**50**
Protons/pulse (x 10^{14})	**1.5**	**2 (2.5 GeV) + 1 (5 GeV)**
Av. Pulse current (mA)	**20**	**40**
Pulse duration (ms)	**1.2**	**0.8 (2.5 GeV) + 0.4 (5 GeV)**

1. REMINDER: Stage 3 (2/2)

Additional option initiated in September 2008 (LHeC workshop in Divonne): use the β=1 part of the SPL for multi-pass acceleration of e+/e- for LHeC…

In any case, any upgrade beyond stage 2 (LP-SPL):

- will depend upon the approval of major new physics programmes [Radioactive Ion beams (EURISOL-type facility) / Neutrino factory / LHeC].
- will be mostly implemented during a series of ordinary shutdowns
- **is unlikely to be in operation before 2020**

2. SPL design (1/6)

Summary of SPL parameters review (2008)

	704 MHz	1408 MHz	352 MHz (spoke) + 1408 MHz
length	**439 m**	**+14%**	+10%
$N_{cavities}$	**239**	**+16%**	+12%
$N_{\beta\text{-families}}$	**2**	**3**	2+1
tr. beam loss	-	-	-
jitter	medium	medium	medium
ε-growth (x/y/z)	5.6/8.2/6.8	6.3/7.8/**12.1**	**1.5/5.3/2.5**
trans. beam loading	-	-	-
BBU (HOM)	$I_{BBU,704}$	**1/(8..128)**	**higher**/**lower**
trapped modes	normal risk	**2..4 higher risk**	?/**higher**
SC gradients	-	-	-
field control		**more complex**	

2. SPL design (2/6)

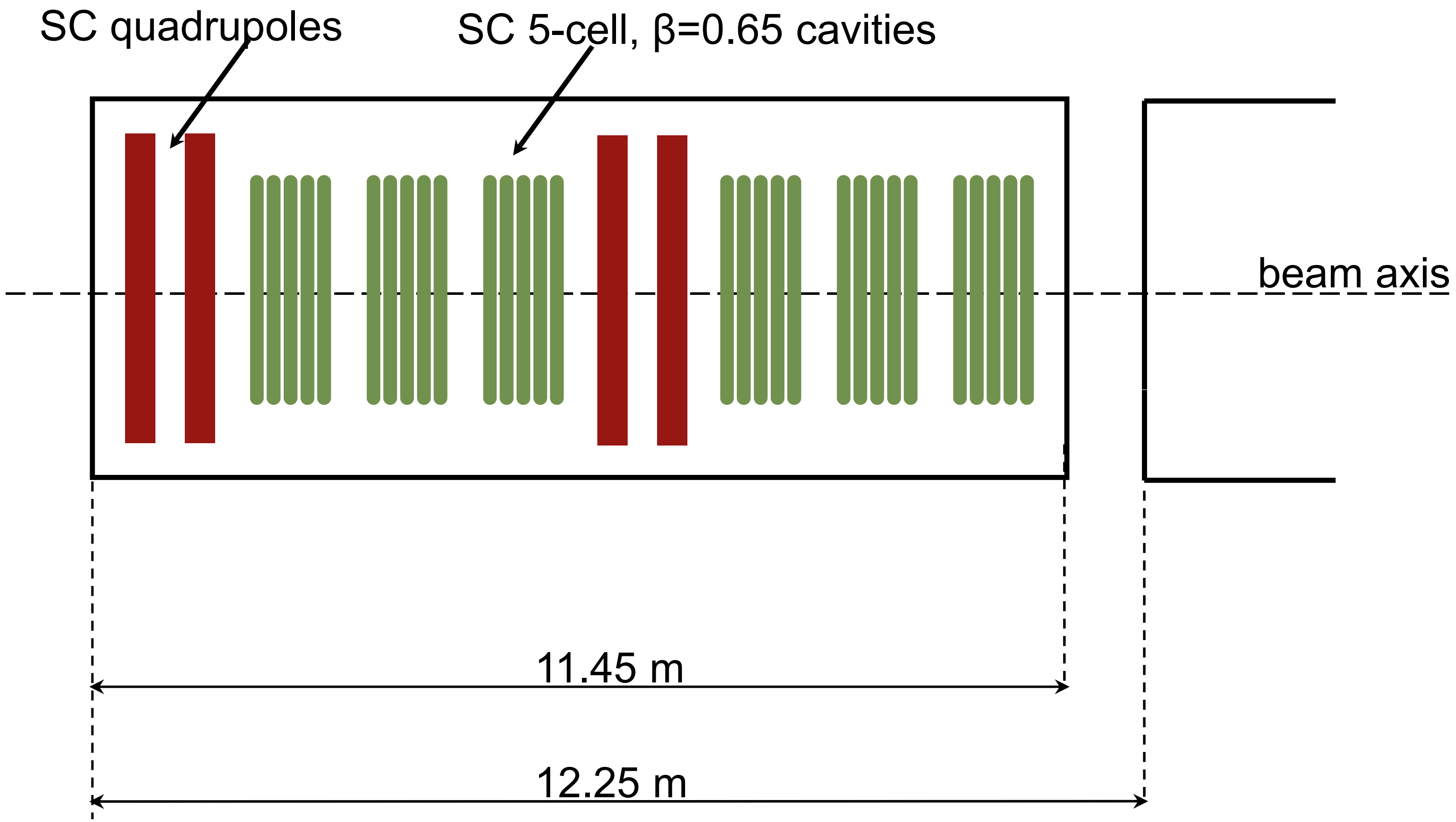
Summary of SPL parameters review (2008)

	704 MHz	1408 MHz	352 MHz (spoke) + 1408 MHz
cryo-modules	follow ILC	follow ILC	2 different types
cooling power @4.5 K	15.3 kW	15.5 kW	?
klystrons	comfortable: MBK	difficult	existing/difficult
RF power coupler	feasible	feasible	feasible
RF power density limit (distribution)	ok	problematic	bulky/problematic
overall power consumption (RF+cryo, nom. SPL)	28 MW	-30%	?
power converter	more bulky	saves tunnel space	-
synergy with ESS	yes	no	no

2. SPL design (3/6)

Basic β=0.65 cryomodule

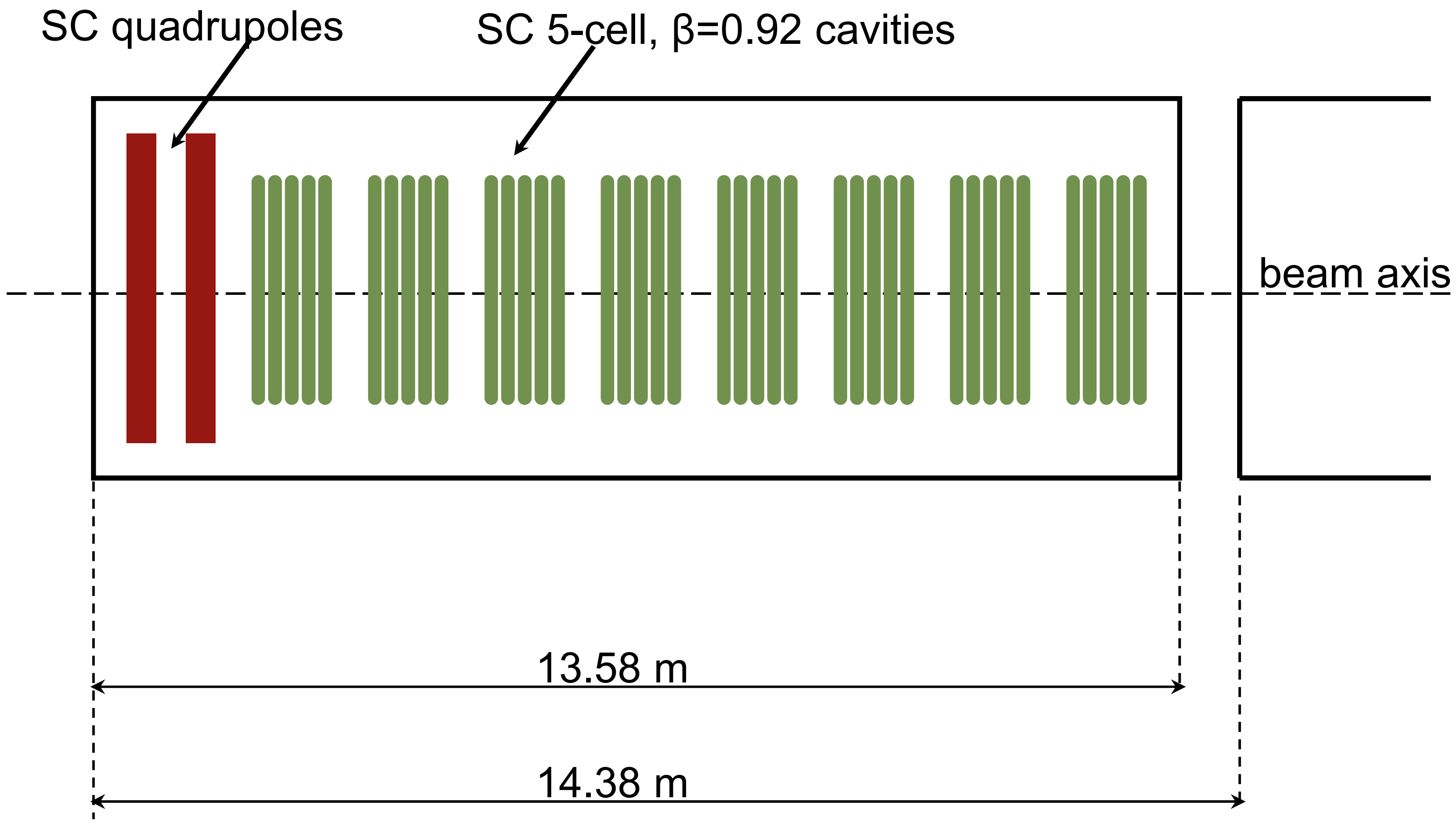
Doublet focusing, 2 periods per module



2. SPL design (4/6)

Basic β=1 cryomodule

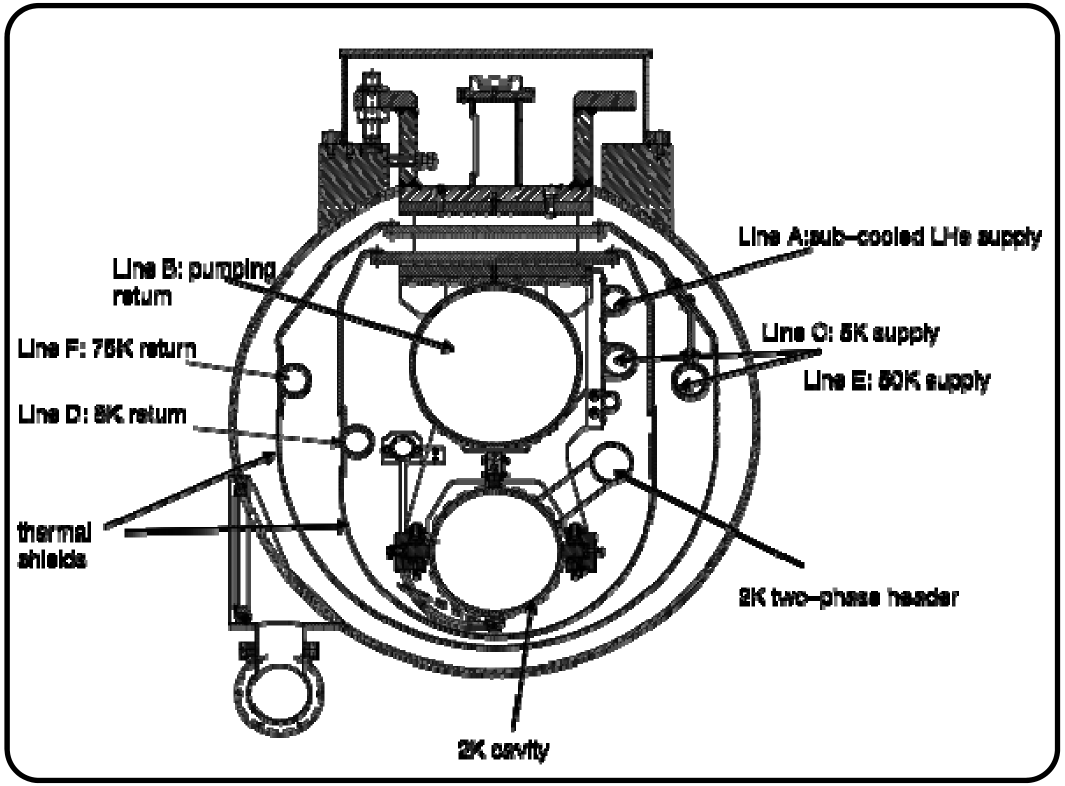
Doublet focusing, 1 period per module



2. SPL design (5/6)

SPL cryomodule design

Principle: start from the TESLA/ILC design...



- long modules with a low number of cold/warm transitions and low static losses,
- cold quadrupoles,
- high packing factor,
- requires high reliability of all components and an SPL specific approach!
- work started within FP7 on a moderate level. Complemented by support of CEA + IN2P3.

2. SPL design (6/6)

SPL cryomodule and RF design

Need to adapt the ILC/TESLA technology to a β < 1 proton linacs:

- design and construct a full-scale cryo-module (adapting the TESLA/ILC approach to 704 MHz),
- test cavities in the cryo-module at full power and full duty cycle (LP-SPL & HP-SPL),
- development 50 Hz, high-power klystron modulators, 704 MHz MBK klystrons seem promising (development by industry),
- test the complete RF system (5 MW pulsed klystron @ 704 MHz, RF splitting: 4 and possibly up to 16 cavities powered by one klystron!),
- test high-power vector modulators, control system, cavity tuning, etc.

3. SPL WORK PLAN (1/3)

- **Linac4 is in construction at the correct location for becoming the SPL front-end (Beam for physics in 2013)**
- **Project proposals (TDR + cost estimates) for LP-SPL and PS2 are due for mid-2011**

Main technical issues for the SPL project proposal:

- **Design optimization (layout, beam loss and collimation…),**
- **Detailed options and modes of operation**
- **Design and test of prototype sc cavities at 704 MHz (25 MV/m @ β=1),**
- **Design and assembly of a full cryomodule (8 cavities),**
- **Design of the high power RF distribution scheme and prototyping of key components,**
- **Design of architecture and algorithm of operation of the LLRF,**
- **Analysis and documentation of safety and environmental impact,**
- **Preparation of Civil Engineering documents for tender.**

3. SPL WORK PLAN (2/3)

Other technical issues:

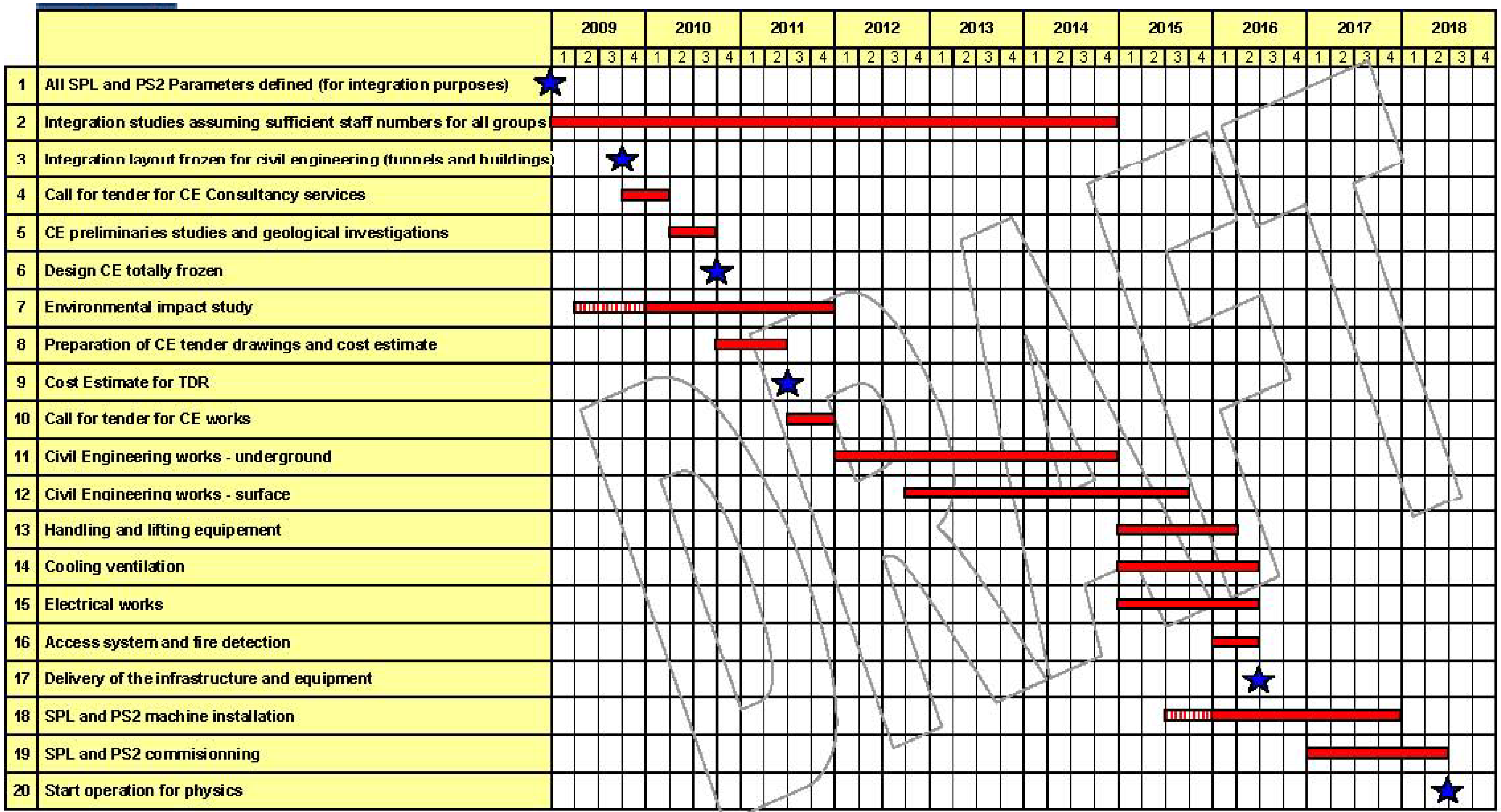
- **LLRF,**
- **Beam instrumentation,**
- **Ion source,**
- **Klystron modulator.**

Other concerns:

- **Implement a 704 MHz high power RF test place with 2 K capability**
- **Upgrade CERN competences and capabilities in SRF.**

3. SPL WORK PLAN (3/3)

Recent planning by Civil Engineering shows that time is very short…



Notes : The 3 years between the first item, "all parameters defined", and the starting of the CE Works is extremely challenging
The planning for EL, CV, HE, … works needs to be approved by various TS corresponding Groups
The planning for items 19 to 20 results from preliminary discussions with R. Garoby and F. Gerigk
Except new FTE, the first financial commitment for either project will be item 5 (~ 1 MCHF). We will try to present the financial commitment planning before end 2008

4. COLLABORATIONS (1/2)

Partial list: negotiations are on-going with other partners having declared interest.

SUBJECT	PARTNERS
Accelerator design / beam dynamics / loss analysis /…	CEA, IN2P3, TRIUMF, Cockcroft Institute, ESS-Lund, Soltan Institute, …
SC cavities @ beta=0.65	IN2P3, TRIUMF
SC cavities @ beta=1	CEA, Stony Brook (?)
Cryomodule design and prototyping	IN2P3, CEA, DESY (?)
High power RF design and prototyping	Cockcroft Institute
Low Level RF algorithm	CEA

4. COLLABORATIONS (2/2)

First meeting of the SPL Collaboration on December 11-12, 2008 at CERN
http://indico.cern.ch/conferenceDisplay.py?confId=44821

Remark: H- ion source, modulators and beam instrumentation are deliberately not on the agenda of this meeting.

MEETING GOALS:

-to review specifications and technical choices + to set deadlines for decision on pending questions,
-to define the precise contribution of each partner (deliverables and planning) and the interactions between partners (names of persons in charge, exchange of information/hardware, planning of meetings, …),
-to propose how to demonstrate 25 MV/m (β=1) and 19 MV/m (β=0.65) before mid-2011
-to list untreated subjects and collect suggestions for addressing them,
- to organize the collaboration (Constitution?),
- to define the dates of the main meetings until end of 2009.

5. PERPECTIVES WITH LOW EMITTANCES (1/5)

The new injectors are designed to provide beam with much higher brightness.

⇓

How much could the LHC characteristics be improved with lower transverse emittances?

5. PERPECTIVES WITH LOW EMITTANCES (2/5)

LUMINOSITY FORMULAE

Luminosity is given by:

$$L = \frac{f_{rev}\gamma}{2r_p} n_b \frac{1}{\beta^*} N_b \Delta Q_{bb} F_{profile} F_{hg}$$

where ΔQ_{bb} = total beam-beam tune shift

$$\Delta Q_{bb} \cong -\frac{N_b}{\varepsilon_N} \frac{r_p}{2\pi\sqrt{1+\phi^2}}$$

with a tight constraint on its maximum value

and ϕ = Piwinski angle

$$\phi = \theta\sigma_Z / (2\sigma^*)$$

5. PERPECTIVES WITH LOW EMITTANCES (3/5)

25 ns bunch spacing + IR Upgrade phase-1 + LINAC4

Maximum luminosity with ε*=3.75 mm.mrad: 1.47 x 10^{34} $cm^{-2}s^{-1}$

	Nominal	Nominal with IR phase 1	Nominal with IR phase 1 and reduced emittance
N_b (x 10^{11})	1.15	1.15	1.15
ε (μm)	3.75	3.75	**2.54**
β*	0.55	0.25	0.25
σ* (μm)	16.58	11.18	9.20
Crossing angle (mrad)	0.290	0.440	**0.360**
σ_z (mm)	75.50	75.50	75.50
φ (Piwinski angle)	0.66	1.49	**1.48**
ΔQ_{bb} head-on	1.00	0.67	**0.99**
Luminosity	1.00	1.47	**2.18**
Luminosity lifetime (h)	22.00	14.95	**10.08**

Maximum luminosity with ε*=2.54 mm.mrad: 2.18 x 10^{34} $cm^{-2}s^{-1}$

5. PERPECTIVES WITH LOW EMITTANCES (4/5)

25 ns bunch spacing + IR Upgrade phase-2 & New Injectors…

	Nominal	Ultimate	Ultimate with β*=0.25 m	Ultimate with β*=0.25 m and reduced emittance	> Ultimate with β*=0.1 m and reduced emittance
N_b (x 10^{11})	1.15	1.70	1.70	1.70	2.36
ε (μm)	3.75	3.75	3.75	**2.60**	**2.60**
β*	0.55	0.50	0.25	0.25	0.10
σ* (μm)	16.58	15.81	11.18	9.31	5.89
Crossing angle (mrad)	0.290	0.315	0.440	**0.365**	**0.580**
σ_z (mm)	75.50	75.50	75.50	75.50	75.50
φ (Piwinski angle)	0.66	0.75	1.49	**1.48**	**3.72**
ΔQ_{bb} head-on	1.00	1.42	0.99	**1.43**	**0.92**
Luminosity	1.00	2.30	3.22	**4.65**	**10.40**
Luminosity lifetime (h)	22.00	14.13	10.11	**6.99**	**4.34**

Maximum luminosity with ε*=2.6 mm.mrad: 10.4 x 10^{34} $cm^{-2}s^{-1}$

5. PERPECTIVES WITH LOW EMITTANCES (5/5)

Additional remarks:

- 25 ns bunch spacing has always been assumed,
- the ratio N/ε in the case of the phase-1 upgrade is the one foreseen with Linac4,
- the ratio N/ε in the case of the phase-2 upgrade is the one foreseen with the new injectors,
- the intensity assumed in the case of the phase-2 upgrade is the one foreseen in the "LPA" scenario…

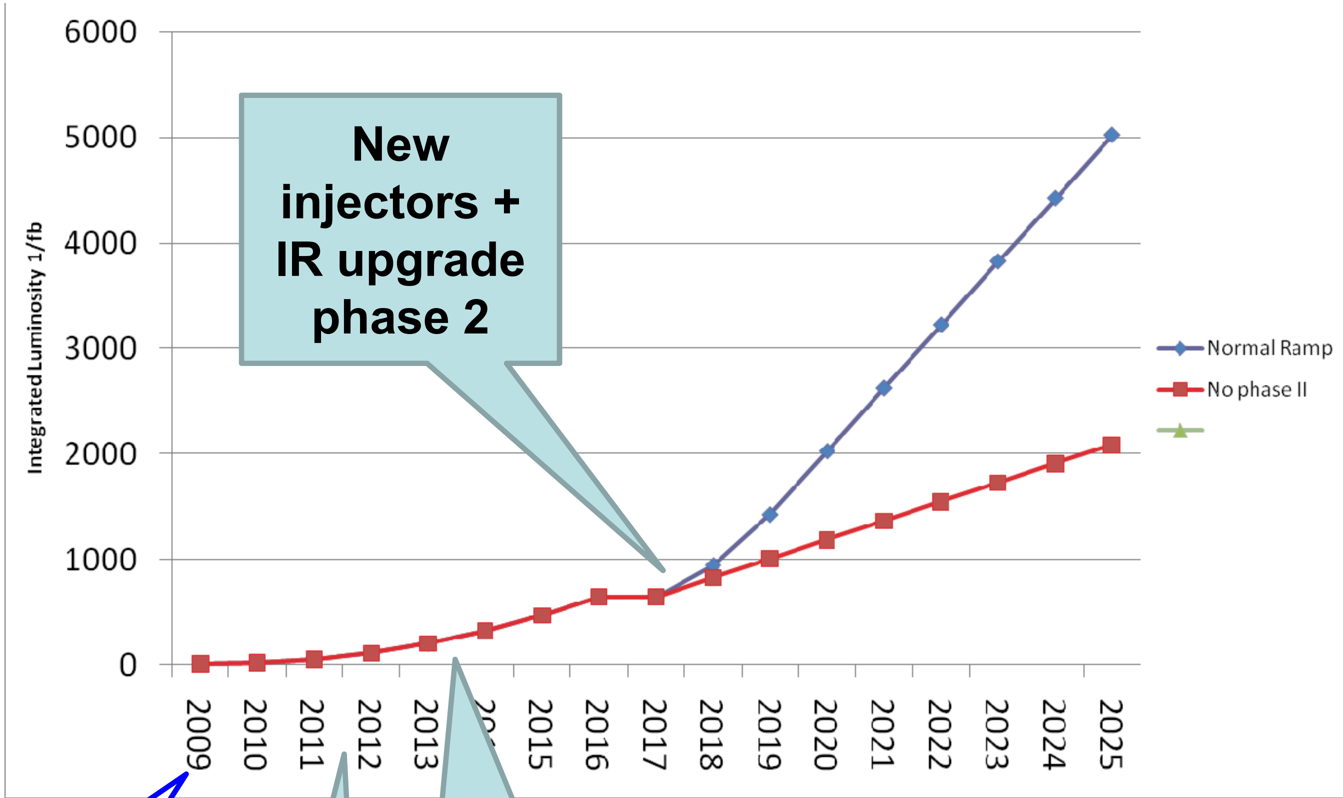
⇓

The new injectors are at the design stage.
It is still time to refine their specifications and make sure that their impact on LHC performance will be maximized!

SPARE SLIDES

PLANS FOR FUTURE INJECTORS: Stage 2 (4/5)

Integrated luminosity in LHC…



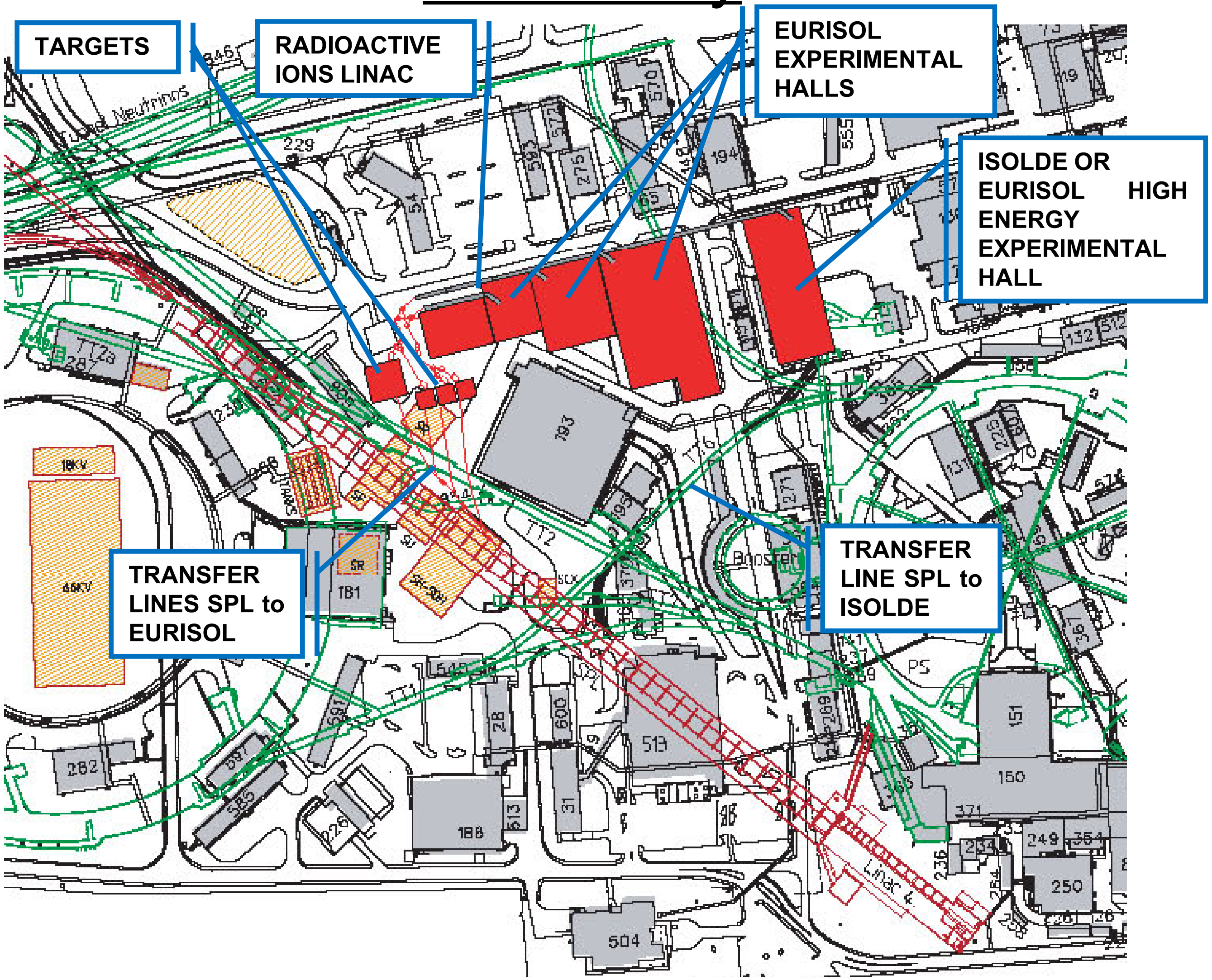
New injectors + IR upgrade phase 2

Early operation

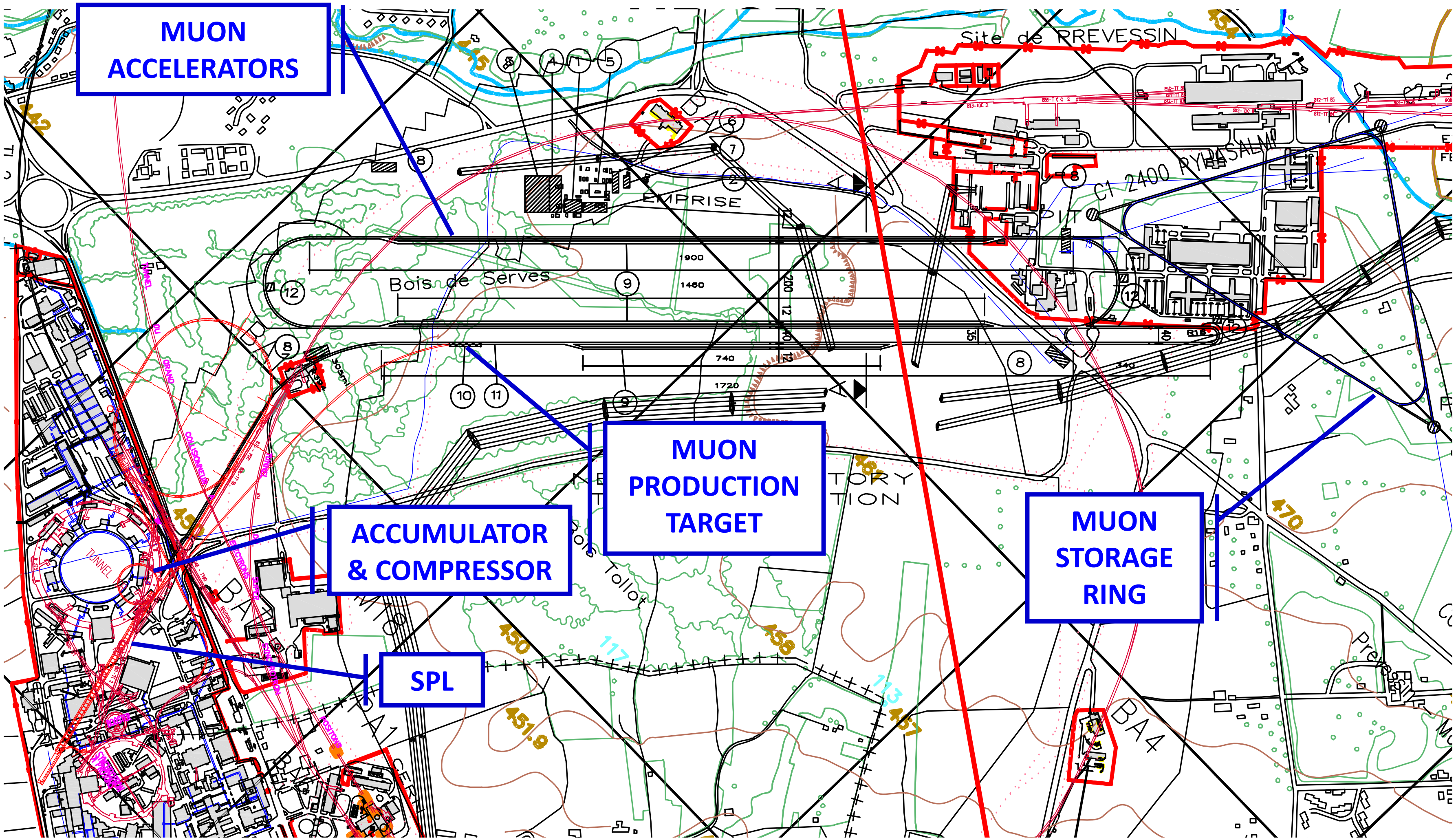
Linac4 + IR upgrade phase 1

Collimation phase 2

RIB facility



Neutrino Factory



4. COLLABORATIONS (3/3)

WORKING GROUPS:

The mandate of the working groups is to fulfill the meeting goals on a subset of subjects.

WG 1: High power RF equipment (RF distribution, amplitude/phase modulators, circulators, loads...)
WG 2: Cavity design (Geometric beta, high power coupler, HOM damper/coupler, tuner...) and construction (Manufacturers, processing facilities, low power RF tests...)
WG 3: Cryomodule and integration (Design, construction, assembly...)
WG 4: Beam dynamics and loss management (Collective effects, H- stripping, collimation...)