Planned upgrades of the CERN injectors

OUTLINE

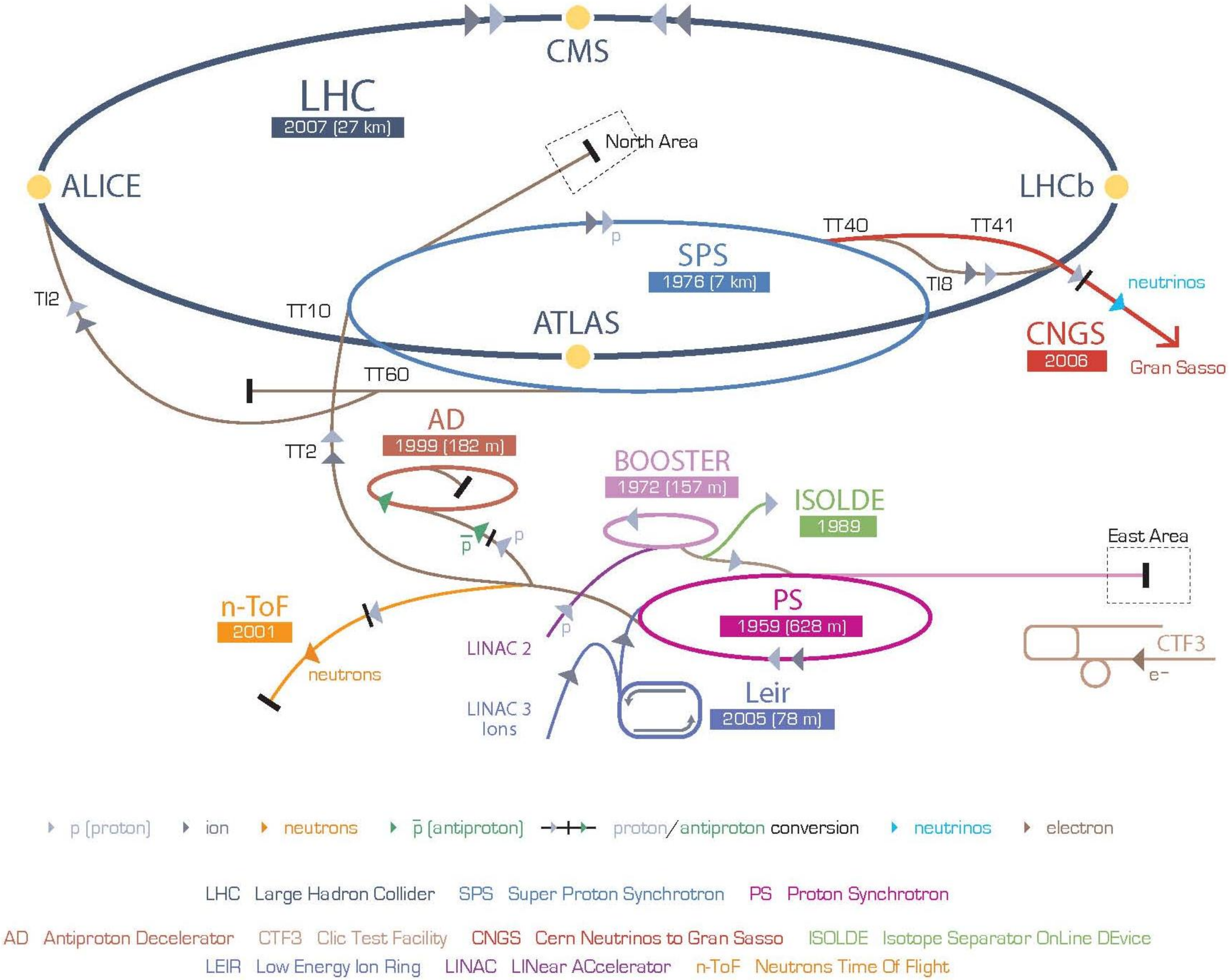
- ✓ Introduction
- ✓ The new linacs
  - Beam characteristics
  - Planning
- ✓ Potential for future RIB facilities at CERN

R. Garoby

20 May 2008

INTRODUCTION

CERN accelerator complex



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Upgrade procedure

1. Lack of reliability:

<u>Ageing</u> 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

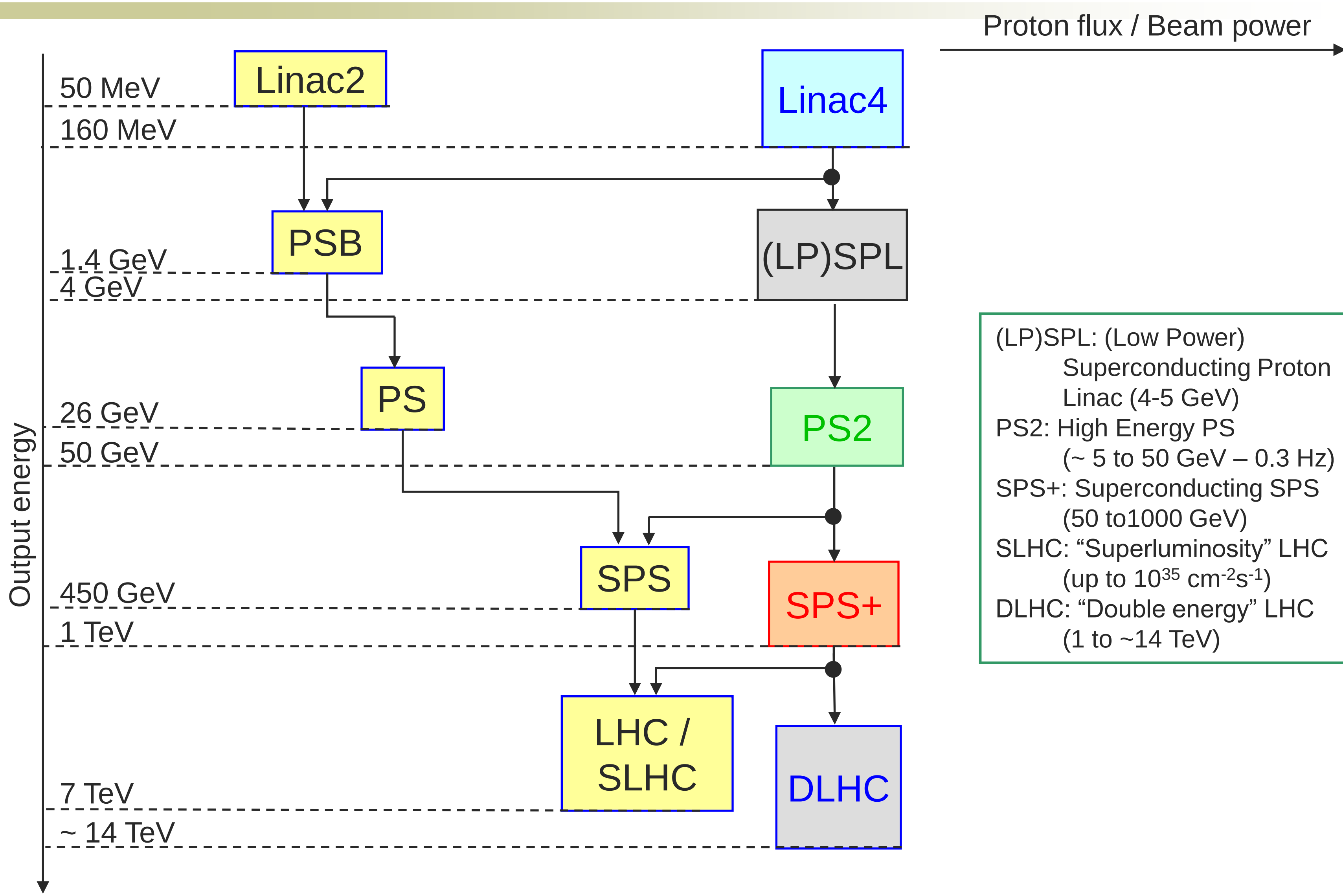
R : mean radius of the accelerator

$\beta\gamma$: 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

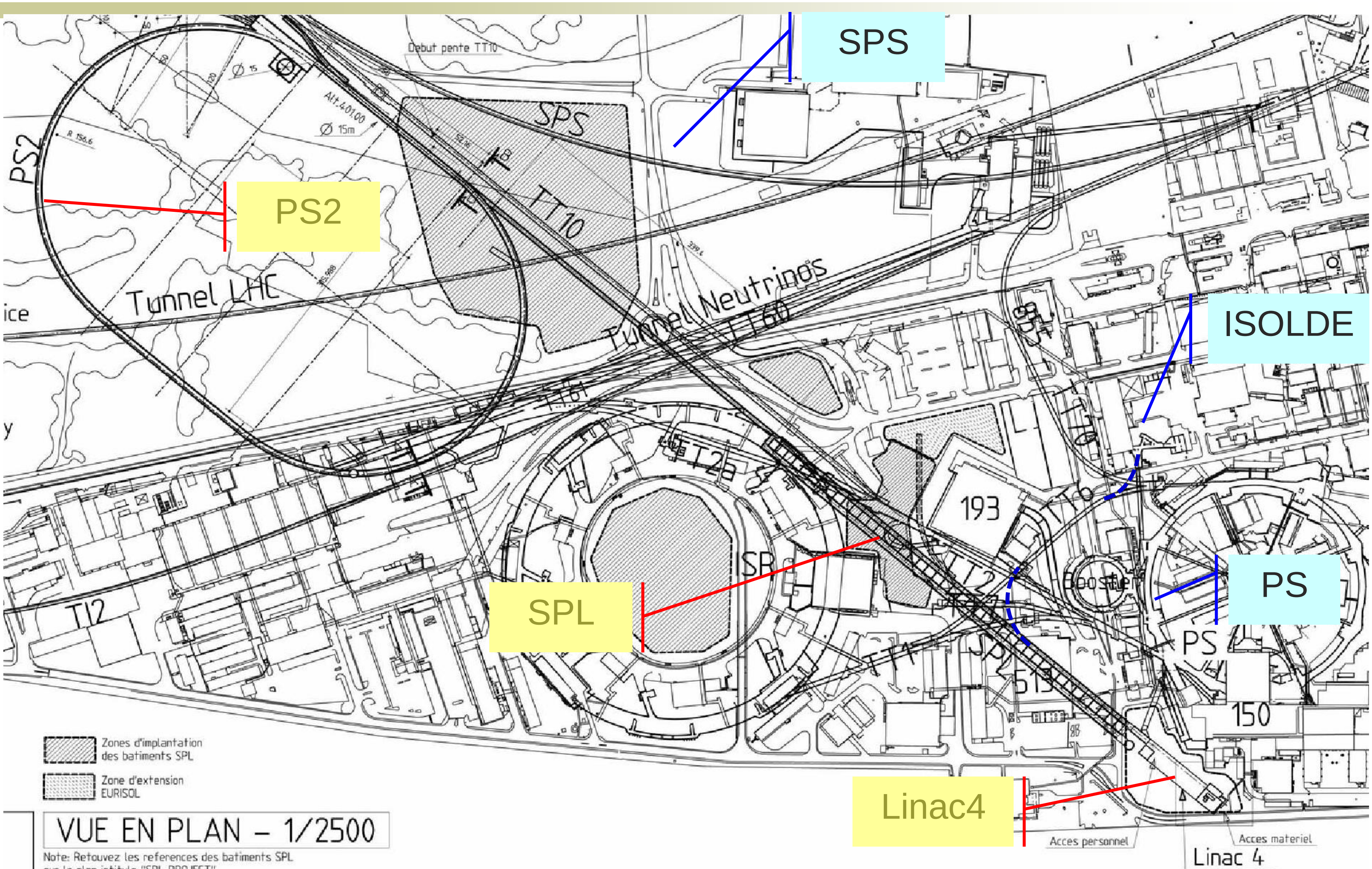
Present and future injectors



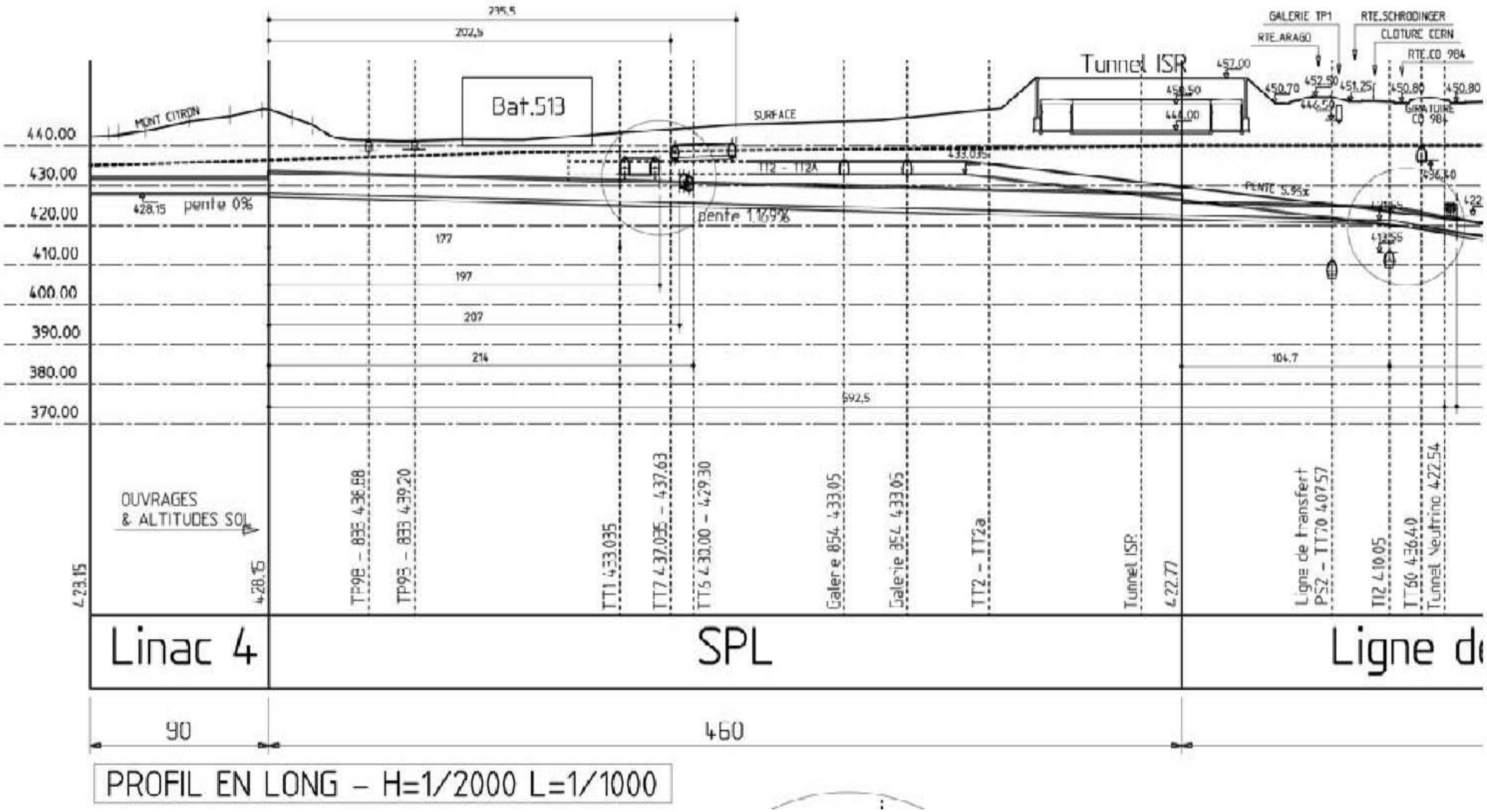
(LP)SPL: (Low Power) Superconducting Proton Linac (4-5 GeV)
PS2: High Energy PS (~ 5 to 50 GeV – 0.3 Hz)
SPS+: Superconducting SPS (50 to1000 GeV)
SLHC: "Superluminosity" LHC (up to 10^{35} $cm^{-2}s^{-1}$)
DLHC: "Double energy" LHC (1 to ~14 TeV)

20 July 2007

Overall layout of the new injectors (1/2)



Overall layout of the new injectors (2/2)



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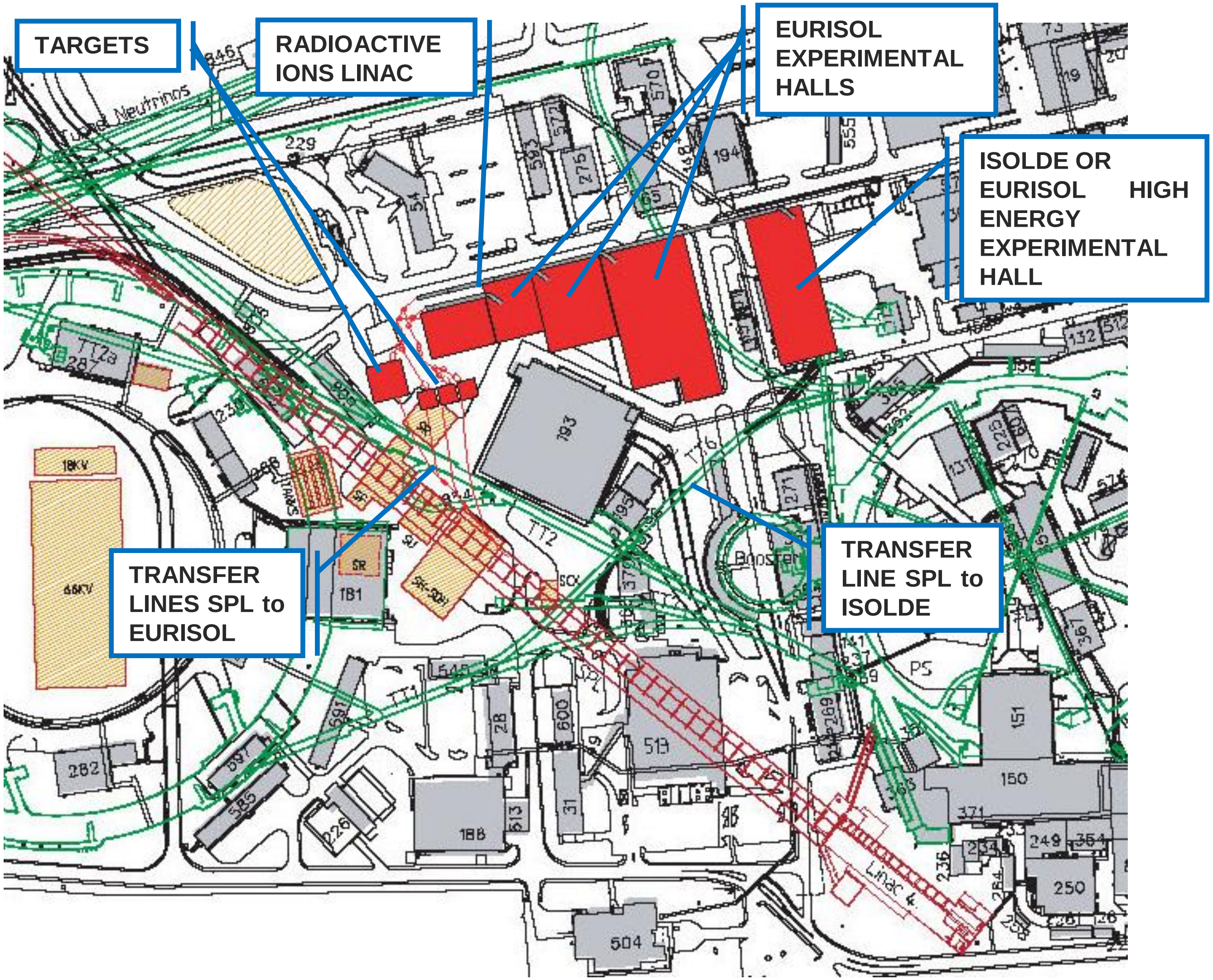
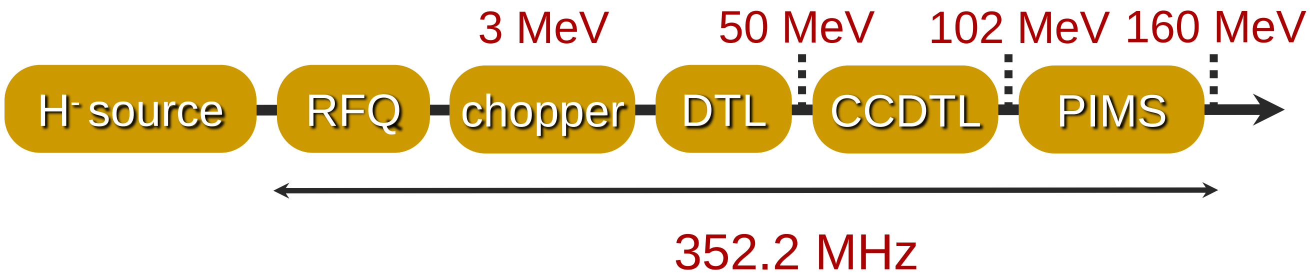
Connections to ISOLDE and EURISOL



THE NEW LINACS

Stage 1: Linac4 (1/2)

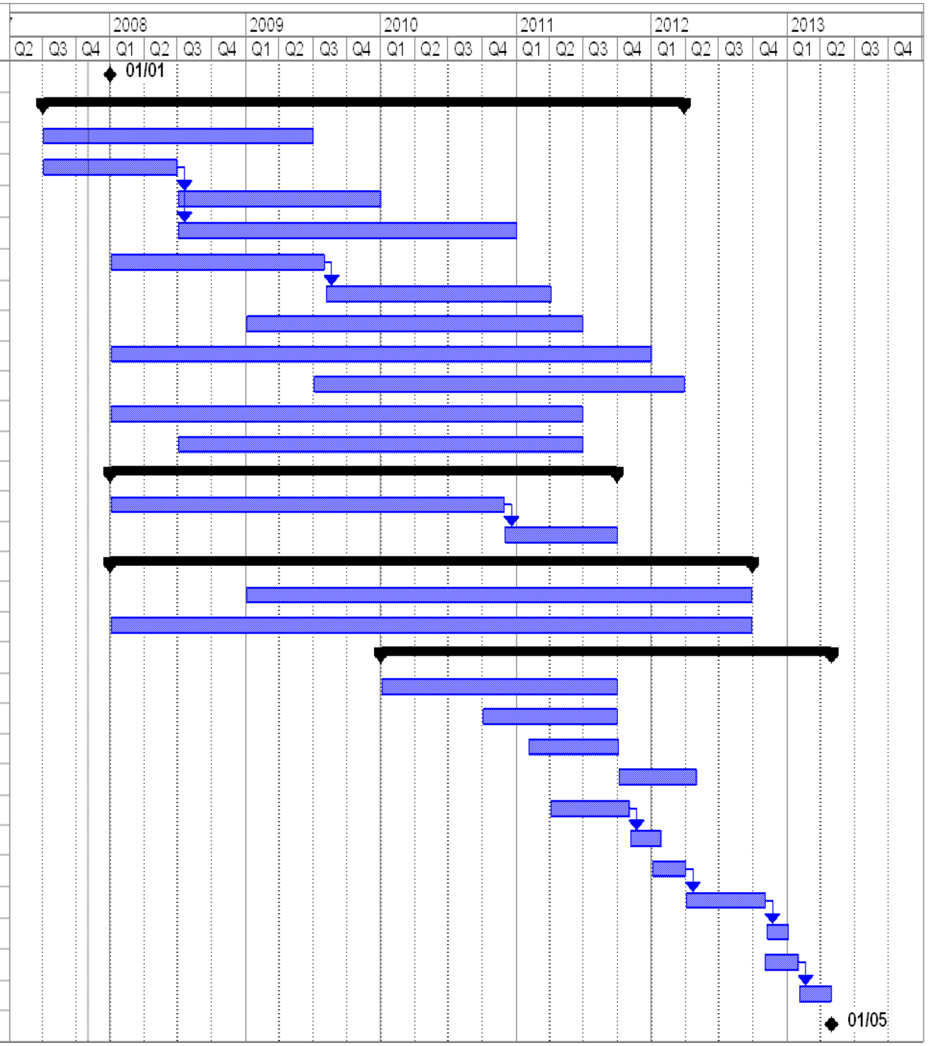


Linac4 beam characteristics

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	$1.0\ 10^{14}$
Transverse emittance (source)	0.2 mm mrad
Transverse emittance (linac)	0.4 mm mrad

Stage 1: Linac4 (2/2)

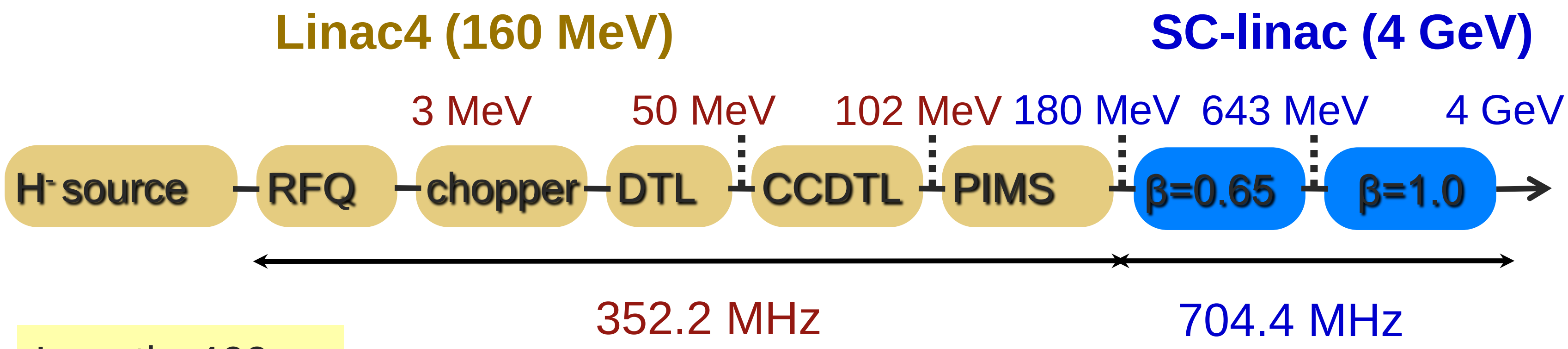
ID	WBS	Task Name
1		**Linac4 project start**
2	2	**Linac systems**
3	2.1	Source and LEBT construction, test
4		Drawings, material procurement
5	2.2	RFQ construction, test
6	2.4	Accelerating structures construction
7		Klystron prototyping
8	2.6.2	Klystrons construction
9	2.6.1	LLRF construction
10	2.7	Beam Instrumentation construction
11	2.8	Transfer line construction
12	2.9	Magnets construction
13	2.10	Power converters construction
14	5	**Building and infrastructure**
15	5.1	Building design and construction
16	5.2,3,4	Infrastructure installation
17	3	**PS Booster systems**
18	3.1	PSB injection elements construction
19	3.2	PSB beam dynamics analysis
20	4	**Installation and commissioning**
21	4.1	Test stand operation (3 + 10 MeV)
22	4.2	Cavities testing, conditioning
23		Cabling, waveguides installation
24		Accelerator installation
25		Klystrons, modulators installation
26		Hardware tests
27		Front-end commissioning
28	4.5	Linac accelerator commissioning
29		Transfer line commissioning
30		PSB modifications
31	4.6	PSB commissioning with Linac4
32		**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**

Stage 2: LP-SPL (1/2)



Length: 460 m

LP-SPL beam characteristics

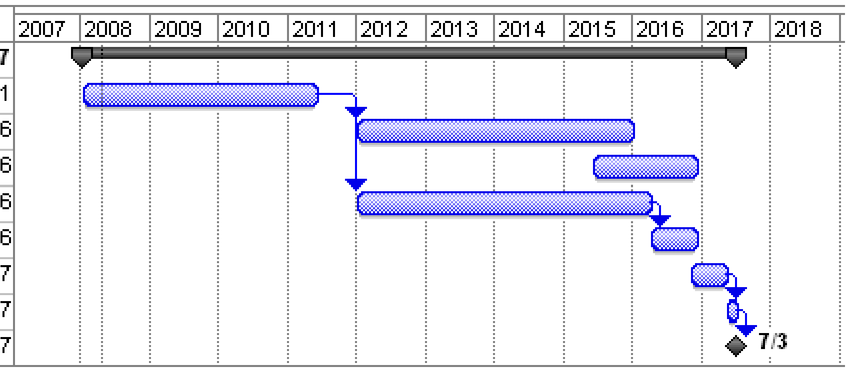
Kinetic energy (GeV)	**4**
Beam power at 4 GeV (MW)	**0.16**
Rep. period (s)	**0.6**
Protons/pulse (x 10^{14})	**1.5**
Average pulse current (mA)	**20**
Pulse duration (ms)	**1.2**

Stage 2: LP-SPL (2/2)

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.

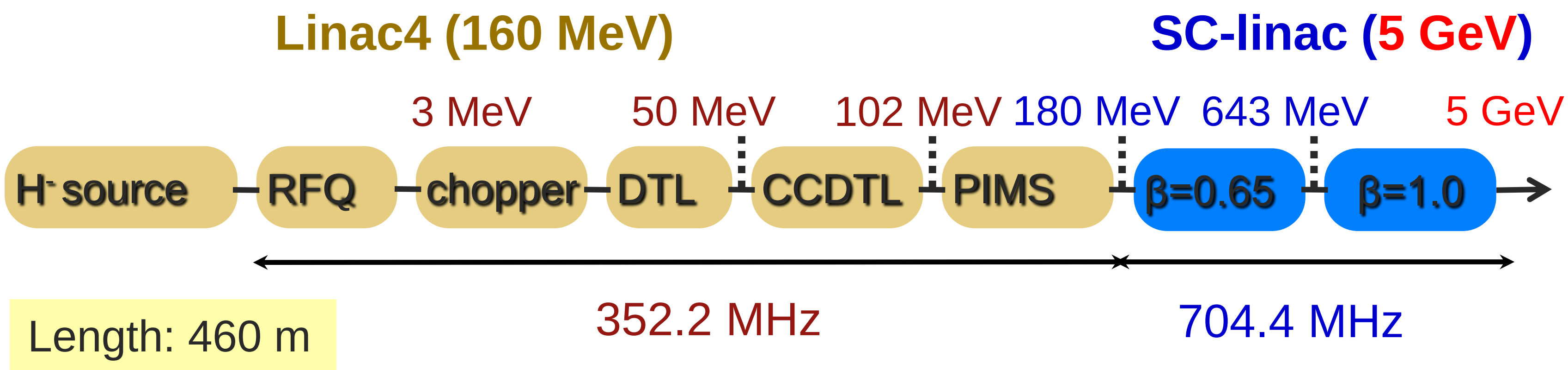
ID	Task Name	Start	Finish
1	**SPL + PS2**	**Mon 1/7/08**	**Mon 7/3/17**
2	Design	Mon 1/7/08	Wed 6/1/11
3	SPL Construction	Mon 1/2/12	Fri 1/1/16
4	SPL beam commissioning	Mon 6/1/15	Fri 12/2/16
5	PS2 construction	Mon 1/2/12	Fri 4/1/16
6	PS2 beam commissioning	Mon 4/4/16	Fri 12/2/16
7	SPS modification	Fri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

Stage 3: HP-SPL (1/2)



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)**

Stage 3: HP-SPL (2/2)

- ✓ The upgrade from LP-SPL to HP-SPL will depend upon the approval of major new physics programmes for Radioactive Ion beams (EURISOL-type facility) and/or for neutrinos (Neutrino factory).
- ✓ Staged hardware upgrade during shutdowns
- ✓ **Earliest year of operation: 2020**

POTENTIAL FOR FUTURE RIB FACILITIES AT CERN

ISOLDE (and REX-ISOLDE)

- Linac4 + PSB (2013):
  - ~ 2x the intensity per pulse (6.4 E13 p/p)
  - Cycling rate increased because of faster filling of the PS
  - Possibly 0.9 s basic period?

- LP-SPL (2017)

Beam energy	**~ 1.4 GeV**
Pulsing rate (0.6 s B.P.)	~ 1.25 Hz
Beam current during pulse	20 mA
Pulse length	1.2 ms
Number of protons/pulse	1.5 E14 p/p
Average beam power	42 kW

EURISOL (1/2)

- Phase 1 with LP-SPL (2017)

Beam energy	~ 2.5 GeV
Pulsing rate (0.6 s B.P.)	~ 1.25 Hz
Beam current during pulse	20 mA
Pulse length	1.2 ms
Number of protons/pulse	1.5 E14 p/p
Average beam power	75 kW

EURISOL (2/2)

- Phase 2a with HP-SPL for EURISOL only

Beam energy	~ 2.5 GeV
Pulsing rate (20 ms B.P.)	~ 50 Hz
Beam current during pulse	20 (40) mA
Pulse length	1.2 ms
Number of protons/pulse	1.5 (3) E14 p/p
Average beam power	3 (6) MW

- Phase 2b with HP-SPL for EURISOL + ν Factory

Beam energy	~ 2.5 GeV
Pulsing rate (20 ms B.P.)	~ 50 Hz
Beam current during pulse	40 mA
Pulse length	0.8 ms
Number of protons/pulse	2 E14 p/p
Average beam power	4 MW

References

"New Initiatives 2008-2011" (1/2)

- Formal request of the CERN direction to the Council in June 2007:

" Scientific Activities of CERN and Budget Estimates for the years 2008-2011 and provisional projections until 2016" – CERN/2728/Rev.

- 3 high priority themes (the study of SPL and PS2 are parts of the 2nd theme together with the construction of Linac4)

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B) Second Theme:

As a high priority, the renovation of the entire old injector complex should be started in order to eliminate the concern about reliability of LHC operation in the longer term and **the technical bottlenecks in the present injection line**. The proposed strategy is firstly to replace the present Linac 2 with a new PS Booster (PSB) injector, Linac 4, and later to replace the PS by a new one (PS2), with a similar cycling rate but capable of 50 GeV. PS2 will probably be fed by a new high beam-current superconducting proton linac (SPL) capable of about 5 GeV. SPL could also be appropriate for a neutrino production facility.

In the period up to 2011, this strategy should thus be implemented by two actions:

- The first is to build Linac 4, capable of 160 MeV instead of 50 MeV and with a better emittance. These features will enhance the ability to operate the LHC reliably at high

"New Initiatives 2008-2011" (2/2)

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- The second, to be executed in parallel to the first, is to push forward the design of PS2 and SPL. The requested effort represents the CERN contribution to attract international partners, typically in the context of FP7 proposals. Despite the comment of the SPC panel, the requested effort for SPL is not felt to be excessive in order to prepare such a large project (see also comment on Linac 4 construction above).
  Estimated P requirement = 30 FTEs for PS2 and 40 FTEs for the SPL.

- A lower priority theme to be financed with 10 MCHF/year in 2010 and after

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D) Fourth Theme:

This Theme includes activities that are of high scientific interest, but which rely only partially on CERN contributions and will require an agreement with outside partners for an amount that is currently unknown. The components of this Theme are:

1) A facility to be (re)built at CERN, profiting from earlier investments (LEP), including additional equipment and a facility for testing superconducting cavities. Projects that would need such a facility include: International Linear Collider, Superconducting Proton Linac; high intensity Neutrino Facility; High Intensity and Energy ISOLDE. This facility would include clean rooms, an electro-polishing facility, cryogenic cooling infrastructure at 4.2 and 1.8 K, RF testing equipment, etc.). The contribution of CERN may be in the range of:
   M + P = 10 MCHF + ~ 20 FTEs.

Long Term Plan [DG's talk after Council approval (slide 46)]

Prospects for scientific activities over the period 2012-2016

Results available from LHC operation during the period 2008-2011 and from the activities proposed above should allow the CERN Council in 2010-2011 to decide on the future of CERN for more than one decade.

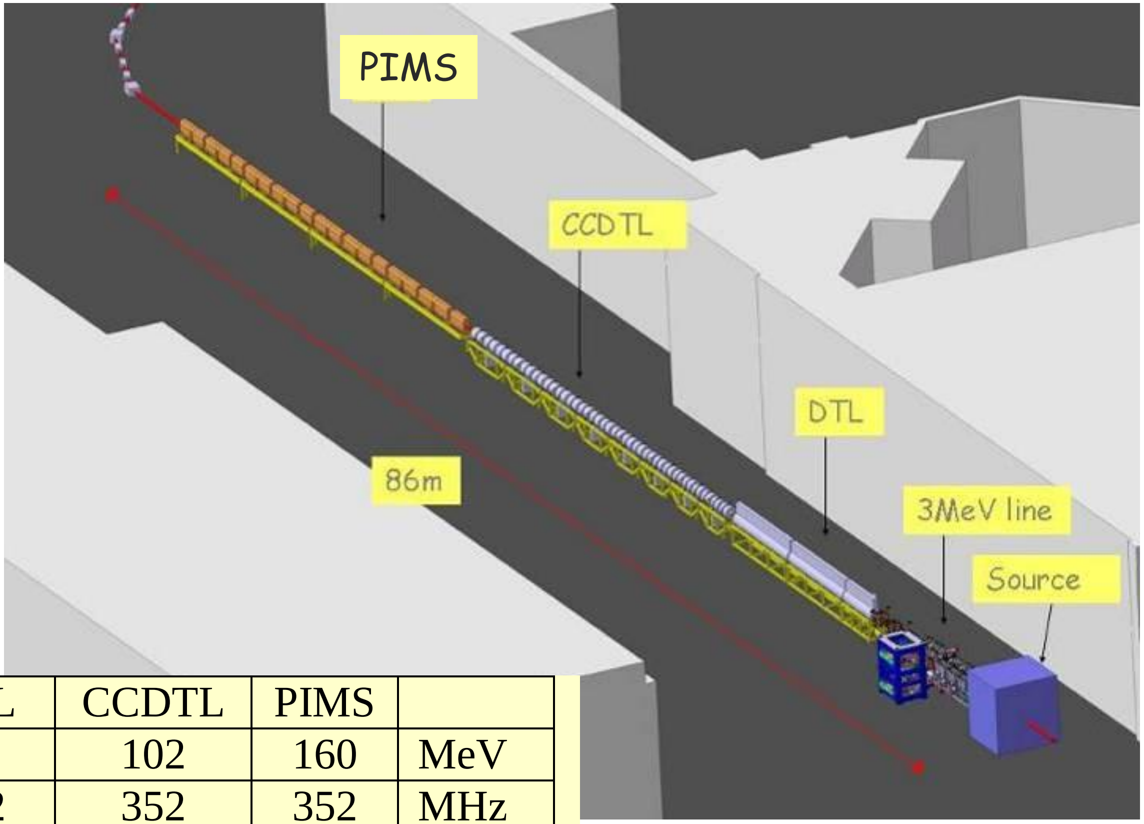
- If results from the LHC, as is highly likely, suggest the need for an increase in luminosity allowing a more extensive exploration of the new territory opened by the LHC, **a decision on the luminosity increase** (new RF system, new magnets for IR, increased cooling, new tracking in detectors, etc.) **will entail a simultaneous decision to build a new injector (SPL and PS) since higher LHC performance cannot be achieved reliably enough without a new injection line.**

The total cost of the investment, which is assumed to be realized in 6 years (2011-2016), is within the range 1'000-1'200 MCHF and will require a staff of 200-300 per year, thus a total budget of about 200-250 MCHF per year.

Linac4 accelerating structures

Linac4 accelerates H- ions up to 160 MeV energy:

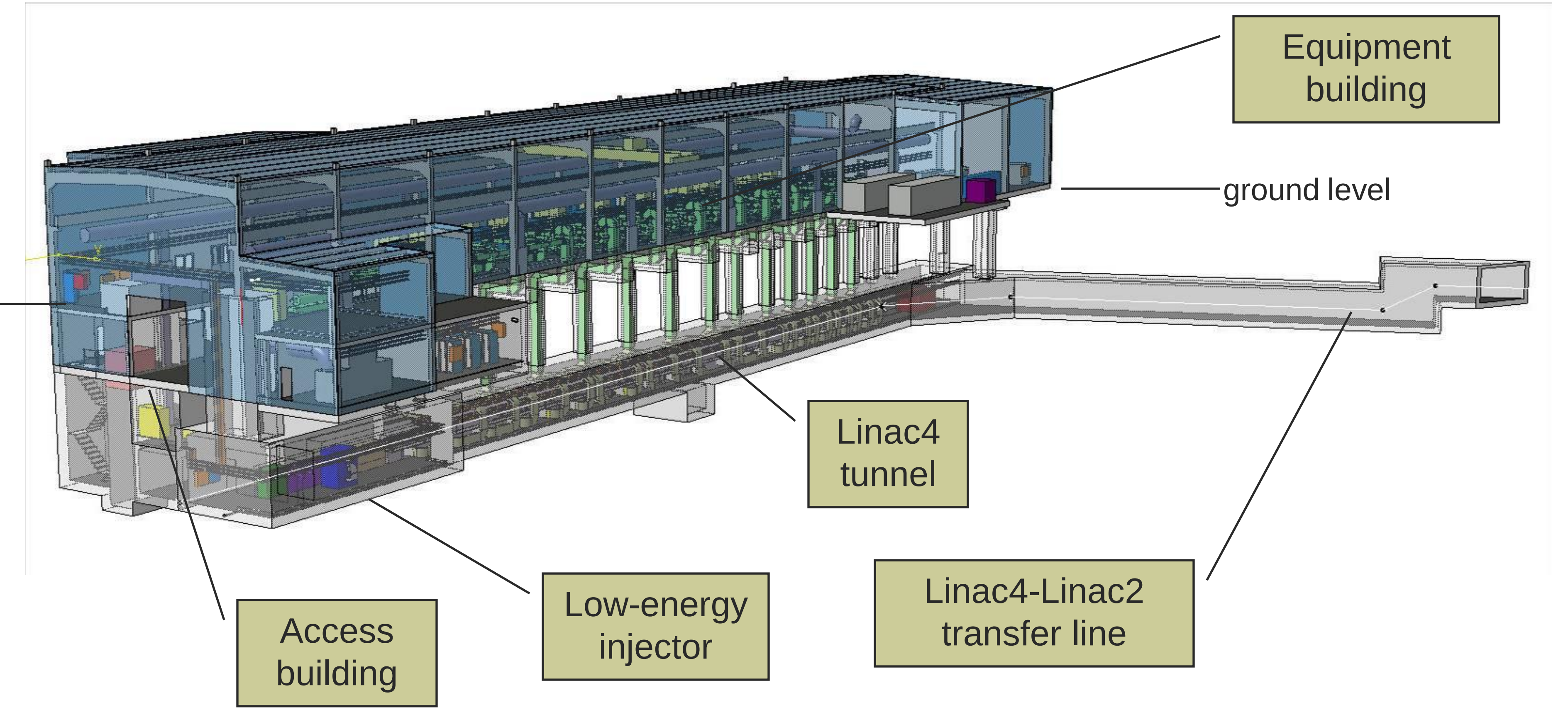
- in about 80 m length
- using 4 different accelerating structures, all at 352 MHz
- the Radio-Frequency power is produced by 19 klystrons
- focusing of the beam is provided by 111 Permanent Magnet Quadrupoles and 33 Electromagnetic Quadrupoles



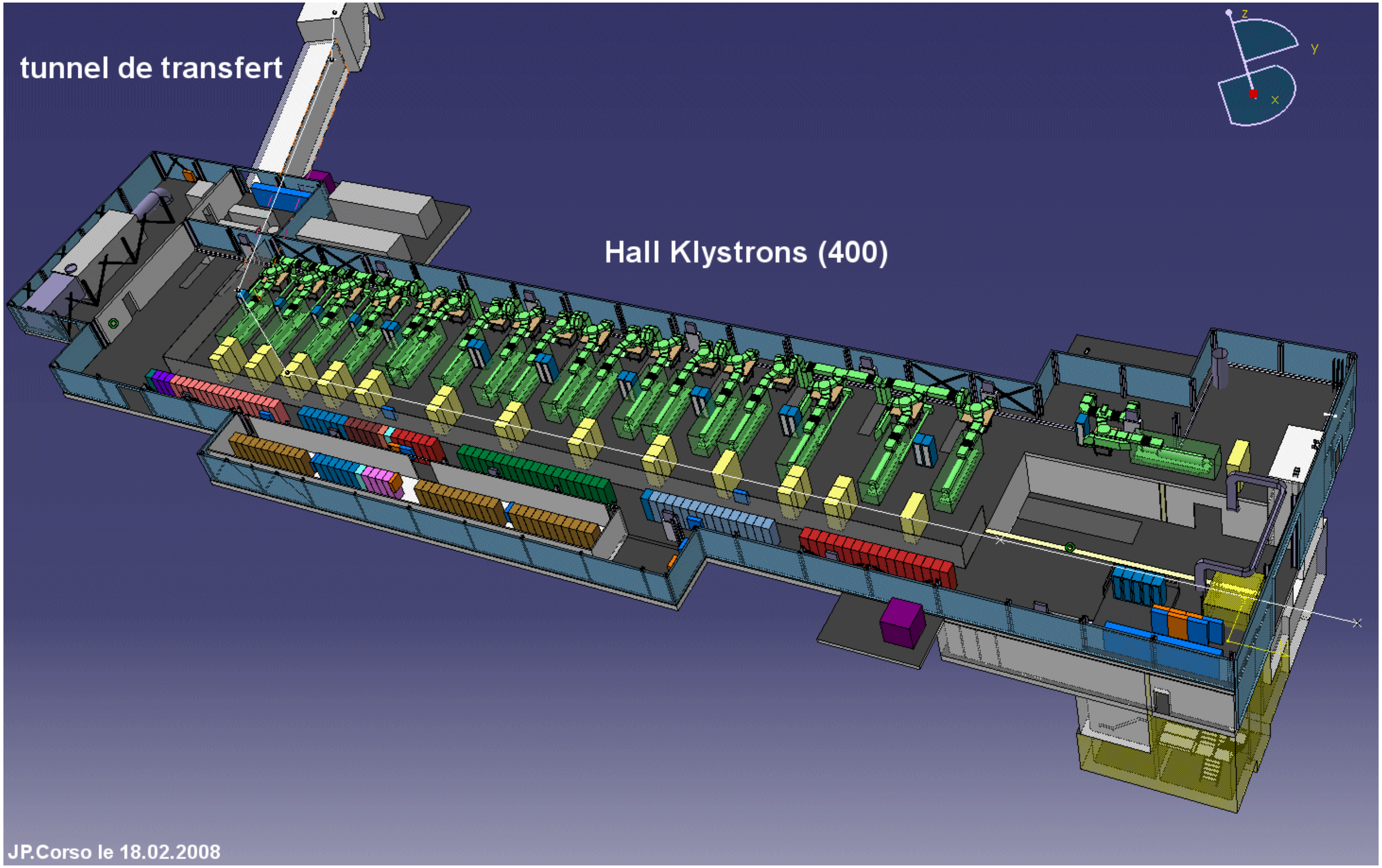
	RFQ	DTL	CCDTL	PIMS	
Output energy	3	50	102	160	MeV
Frequency	352	352	352	352	MHz
No. of resonators	1	3	7	12	
Gradient E_0	-	3.2	2.8-3.9	4.0	MV/m
Max. field	1.95	1.6	1.7	1.8	Kilp.
RF power	0.5	4.7	6.4	11.9	MW
No. of klystrons	1	1+2	7	4+4	
Length	6	18.7	25.2	21.5	m

A 70 m long transfer line connects to the existing line Linac2 - PS Booster

Linac4 civil engineering

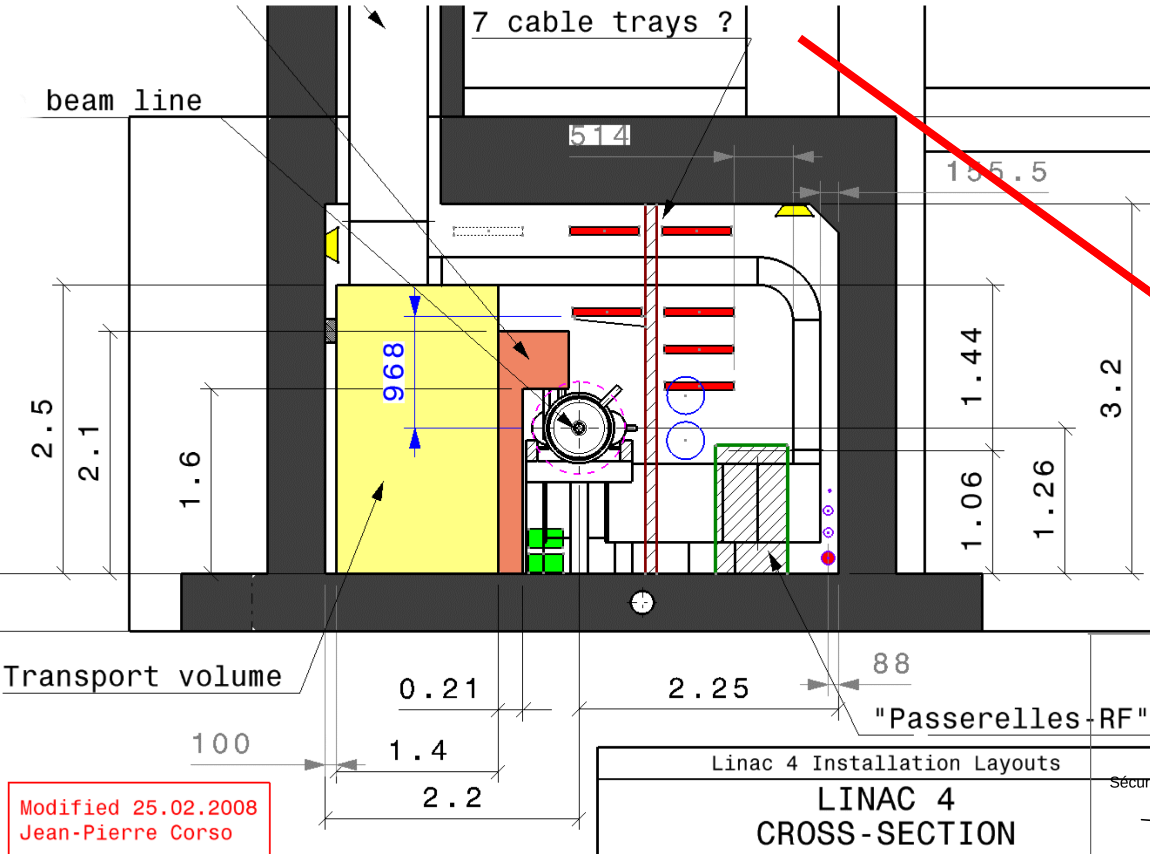


Equipment Hall (Bld. 400)

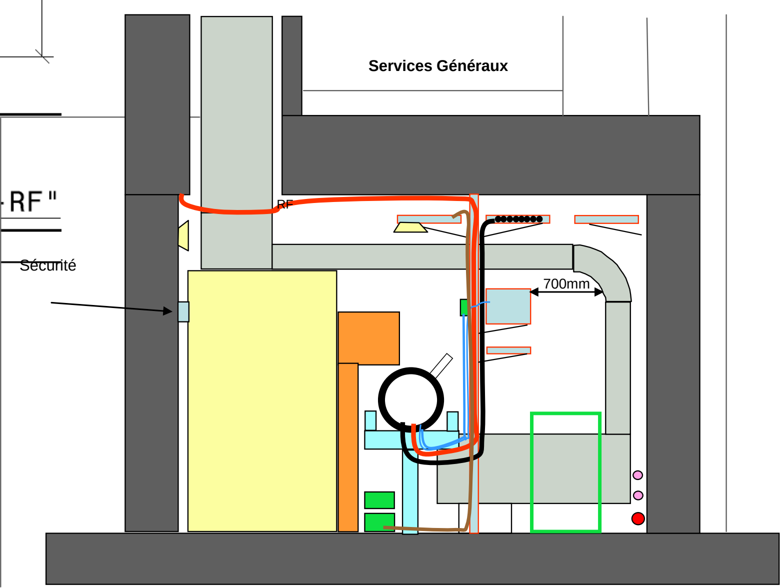


False floor 500mm (all along equipment hall)

Tunnel cross-section



Final position of cable trays:



Linac4 Building (400)