Linac4
parameters and basic design

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Linac4 MAC – 29.01.2008

Linac4 – historical background

1996: first proposal of a Superconducting Proton Linac (SPL) at CERN, using the LEP accelerating system (cavities + RF) for a high power linac, with injection into the PS at 2 GeV.

2000: SPL "Conceptual Design Study".

2001: idea to build in a first stage the warm part of the SPL (120 MeV) in the old PS South Hall and use it to inject H^- into the PSB.

2003: energy up to 160 MeV, called "Linac4" (4th linac to be built at CERN)

2004: start Linac4 R&D:

- EU co-funded Activity on high-intensity linacs (HIPPI), to build chopper line and develop accelerating structures (2004-08).
- Agreements with France to use the IPHI RFQ for Linac4 and with ISTC to finance 3 prototypes of accelerating structures in Russia.

2006: first draft of "White Paper", including Linac4 construction. Linac4 Technical Design Report issued December 2006.

2007: define a new location for Linac4, permitting extension to LP (Low-power)-SPL. Approval of White Paper by CERN Council (June).

"White Paper" - boundary conditions

"White Paper": additional programme for CERN, to be implemented in 4 years (2008-11).

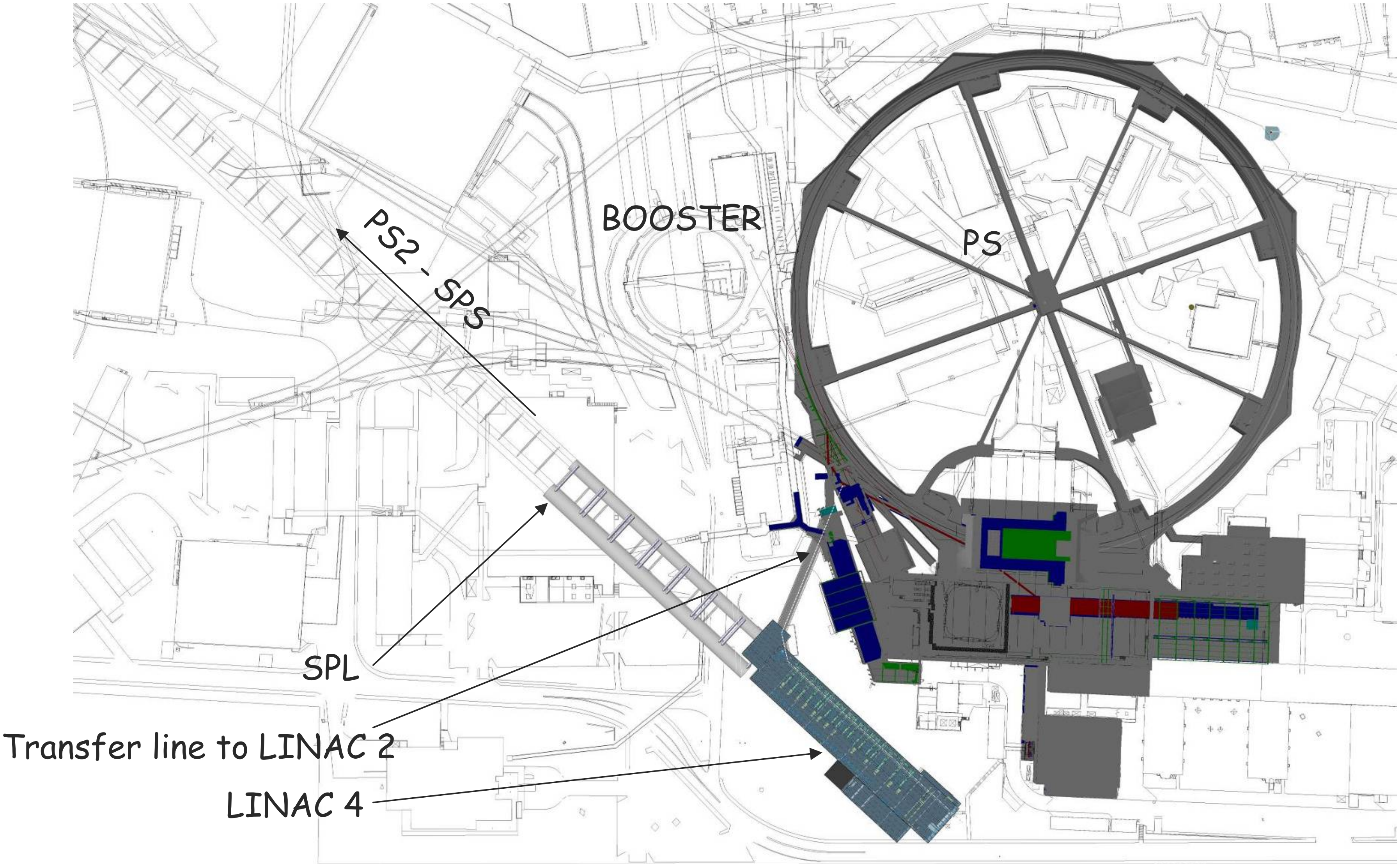
☞ First draft of the White Paper prepared in April 2006. It includes construction of Linac4, allocating 55 MCHF and 115 MY: rough estimate made at the time, considering construction in the existing South Hall, which remained in the approved version of WP.

☞ White Paper slowly through the approval process, until June 2007 (final approval).

☞ Main change to the project since preparation of the White Paper: decision to place Linac4 in a new building, from where it can be easily extended to the SPL. This requires additional (CERN) resources and extends the project to 5 years (2008-12).

☞ End of the project foreseen in May 2013 (end of PS Booster commissioning with Linac4 beam). Further extensions in time would delay the achievement of the White Paper programme and the overall renovation of the LHC injectors.

Linac4: connection to PS Booster and SPL



The 3 lives of Linac4

Linac4 is foreseen to operate in 3 different modes:

1. Injector to PSB (2013-*2017?):* 160 MeV, 1.1 Hz, 40 mA, 400 ms.
2. Injector to LP-SPL *(2017-2020?):* 180 MeV, 2 Hz, 20 mA, 1.2 ms
3. Injector to HP-SPL *(if approved, >2020):* 180 MeV, 50 Hz, 40 mA, 400 ms
   - ☞ Upgrade in energy and connection to LP-SPL around 2016
   - ☞ Upgrade in beam power after 2020

Main consequences on the design:

1. Shielding dimensioned for the high beam power operation (1 W/m beam loss).
2. Accelerating structures and klystrons dimensioned for high duty operation.
3. Power supplies, electronics and infrastructure (water, electricity) dimensioned only for low beam power operation (PSB, LP-SPL), will be replaced for HP-SPL
4. Space provided at the end of the linac for installing additional accelerating structures and for the connection to the SPL

Components are specified for one or the other operating mode !

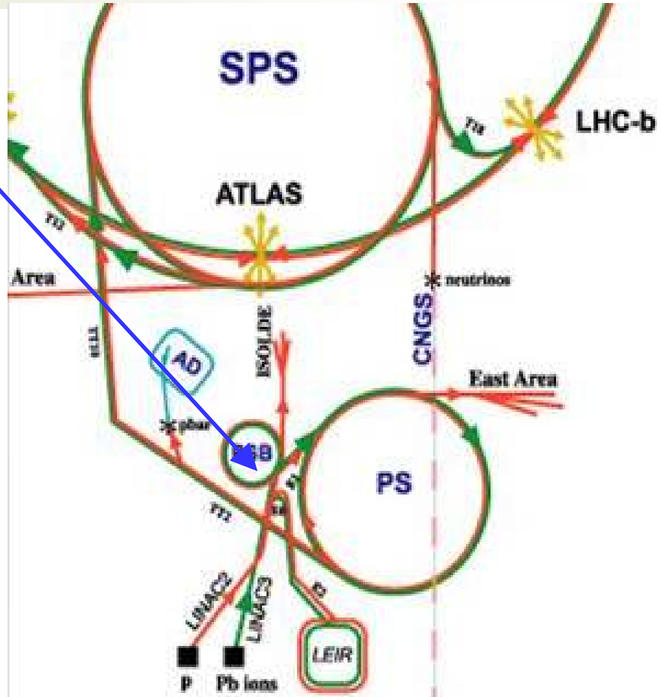
Linac4 for the PS Booster (PSB)

Bottleneck for higher brightness at PSB injection: Incoherent space charge tune shift dominates injection process.

Present scheme → LHC nominal beam in PS with 3x1x2 PSB bunches (3 rings x 1 bunch x 2 batches), at the limit of what can be achieved by the injectors.

New scheme with Linac4 → increase bunch density in the PSB by a factor 2, in order to:

1. Make nominal LHC beam in single batch (simpler operation).
2. Gain a margin for reaching the ultimate LHC bunch population (50% higher) in single or double batch.



☞ *Incoherent tune shift* at injection $\Delta Q \propto I/\beta\gamma^2$ → keep same tune shift with twice the intensity, increasing $\beta\gamma^2$ by factor 2 → injection energy from 50 to 160 MeV.

☞ Additional advantages with Linac4:

1. H^- charge exchange injection.
2. Chopper at low energy → remove linac bunches at the edges of PSB longitudinal acceptance → reduce loss and increase flexibility at capture in PSB.
3. More features to reduce beam loss (collimation, longitudinal painting).
4. Modern machine, less operational concerns (Linac2 vacuum problems, RF tubes availability,…)

Linac4 design parameters

Ion species	H−	
Output Energy	160	MeV
Bunch Frequency	352.2	MHz
Max. Rep. Rate	2	Hz
Chopper Beam-on Factor	62	%
Chopping: 222 transmitted /133 empty buckets		
N. particles per pulse (for PSB)	1.0	$\times 10^{14}$
Max. Beam Pulse Length	1.2	ms
Max. Beam Duty Cycle	0.24	%
Pulse Length for PSB	400	μs
Linac pulse current	40	mA
RFQ output current	70	mA
Source current	80	mA
Source transv. emittance	0.2	π mm mrad
Linac transv. emittance	0.4	π mm mrad

Max. rep. rate for accelerating structures 50 Hz

H^- + higher injection energy (factor 2 in $\beta\gamma^2$) → double bunch population in PSB.

Allows to re-use LEP RF components: klystrons, waveguides, circulators.

Limit of LP-SPL

Max. current defined by high intensity experiments (ISOLDE)

Emittance required for LHC and SPL beams

For HP-SPL

Linac4 challenges

1. First challenge of Linac4 is RELIABILITY: must operate ~6000 hours/year with a fault rate comparable to Linac2, ~1.5% of scheduled beam time.
2. Control of transverse and longitudinal EMITTANCE GROWTH is of paramount importance for clean PSB and SPL injection.
3. Careful LOSS CONTROL to prepare for the SPL mode of operation $\rightarrow$ uncontrolled beam loss <1 W/m in SPL mode $\rightarrow$ <0.1 W/m in PSB injection mode (at 160 MeV, 1.5×10^{-5}/m loss rate).
4. Keep the COST of the machine within what is acceptable in the critical post-LHC period.

Linac4 Layout

45keV → RFQ; 3MeV → CHOPPER; 3MeV → DTL; 50MeV → CCDTL; 102MeV → PIMS; 160MeV

H-	RFQ	CHOPPER	DTL	CCDTL	PIMS
RF volume source (DESY type)	Radio Frequency Quadrupole 352 MHz 3 m 1 Klystron 540 kW	Chopper Line 352 MHz 3.6 m 11 EMquad 3 cavities	Drift Tube Linac 352 MHz 18.7 m 3 tanks 3 klystrons 4 MW 111 PMQs	Cell-Coupled Drift Tube Linac 352 MHz 25 m 21 tanks 7 klystrons 6.5 MW 21 EMQuads	Pi-Mode Structure 352 MHz 22 m 12 tanks 8 klystrons ~12 MW 12 EMQuads

Total Linac4:
80 m, 18 klystrons

Ion current: 40 mA (avg. in pulse), 65 mA (bunch)

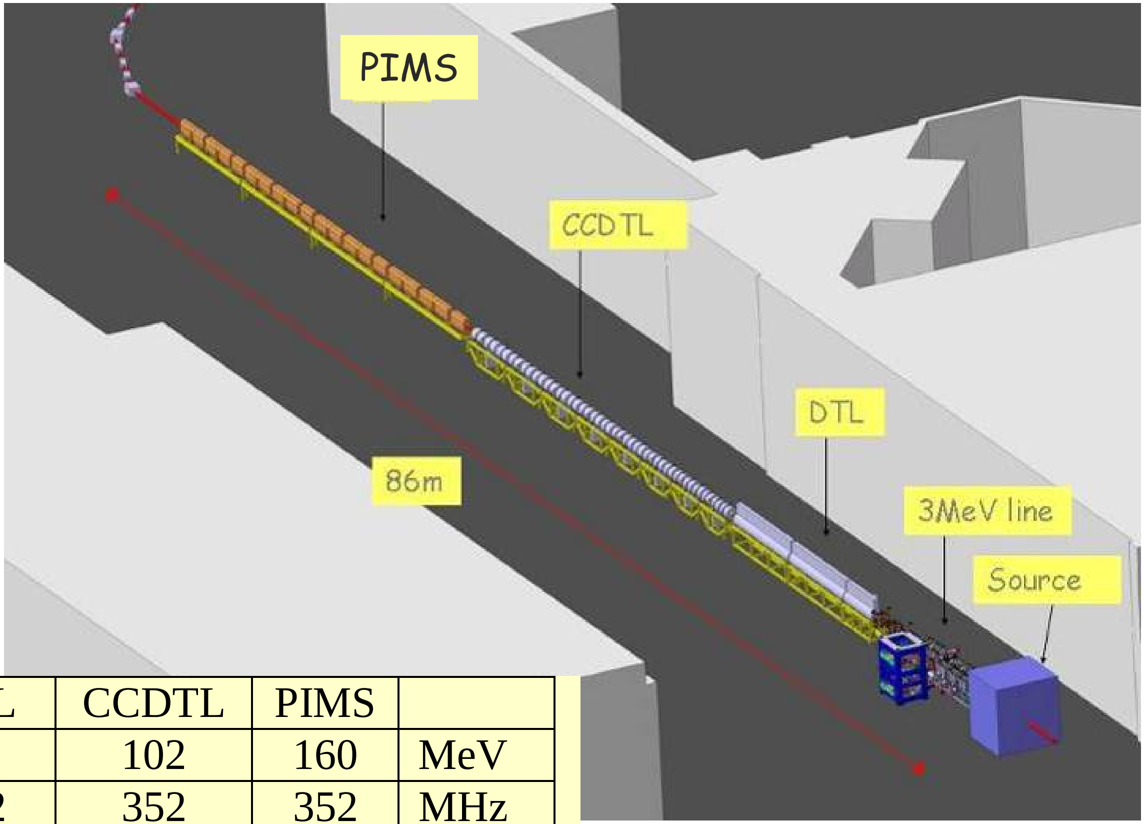
RF Duty cycle:
0.1% phase 1 (Linac4)
3-4% phase 2 (SPL)
(design: 10%)

4 different structures, (RFQ, DTL, CCDTL, PIMS)

Linac4 accelerating structures

Linac4 accelerates H- ions up to 160 MeV energy:

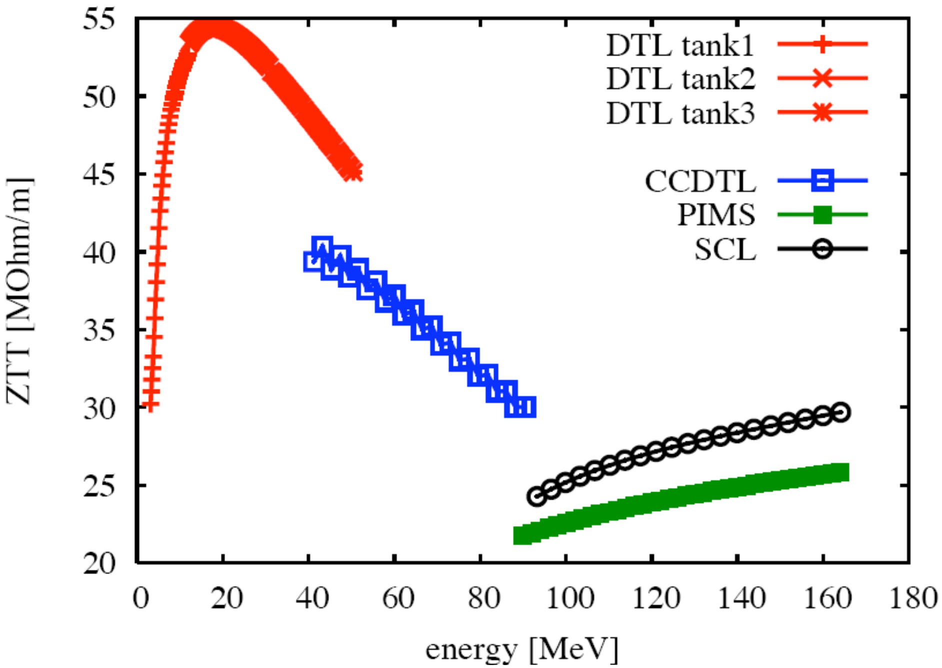
- in about 80 m length
- using 4 different accelerating structures, all at 352 MHz
- the Radio-Frequency power is produced by 19 klystrons
- focusing of the beam is provided by 111 Permanent Magnet Quadrupoles and 33 Electromagnetic Quadrupoles



	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

Accelerating Structures – basic principles



	E_0 (MV/m)	Max. field (Kilpatrick)	E_0 (MV/m, cost optimum for 10 yrs. op.)
DTL	3.2	1.6	4.3
CCDTL	2.8-3.9	1.7	3.1
PIMS	4.0	1.8	2.7

1. Distributed focusing by PMQs (Permanent Magnet Quadrupoles) at low energy, then go to conventional EMQs when less constraints of space, for flexibility-reliability.
2. Standard frequency of 352 MHz all along Linac4.
3. Maximum RF efficiency (shunt impedance ZT^2) → 3 different RF structures (two 0-mode, one π-mode).
4. High accelerating gradients because of space constraints, but still in a "safe" range (<1.8 Kilpatrick peak surface field in linac, <1.95 in RFQ).
5. Sufficient safety margins for RF: 25% between cavity design power and klystron peak power (losses in waveguides, regulation) + 20% between design power and ideal power (from simulations).

Changes to Linac4 design in 2007

Since the Technical Design Report of December 2006:

1. Single frequency: the 704 MHz Side Coupled Linac replaced by the 352 MHz PI-Mode Structure (PIMS)

2. Revised klystron layout with the use of 2 types of klystrons at 352 MHz: 1.3 MW LEP-type and new pulsed units at 2.6 MW.

3. Revised accelerating gradients and safety margins for power to cavities.

4. New 3-m long RFQ instead of the 6-m CW IPHI RFQ.

+ improvements to accelerating structures, diagnostics, etc.

☞ The general design is now frozen.

New TDR to prepare in 2008.