Linac4

M. Vretenar for the Linac4 design team

HHH Workshop – 24.11.2008

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, improving the **beam brightness** in the PS complex.

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

2004: start Linac4 **R&D**,

- started CARE Activity on high-intensity linacs (HIPPI), for (2004-08).
- Agreements with France (IPHI RFQ) and with ISTC (prototypes in Russia).

2006: first draft of “White Paper”, including Linac4 construction in the frame of **LHC Upgrade** plans. 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).

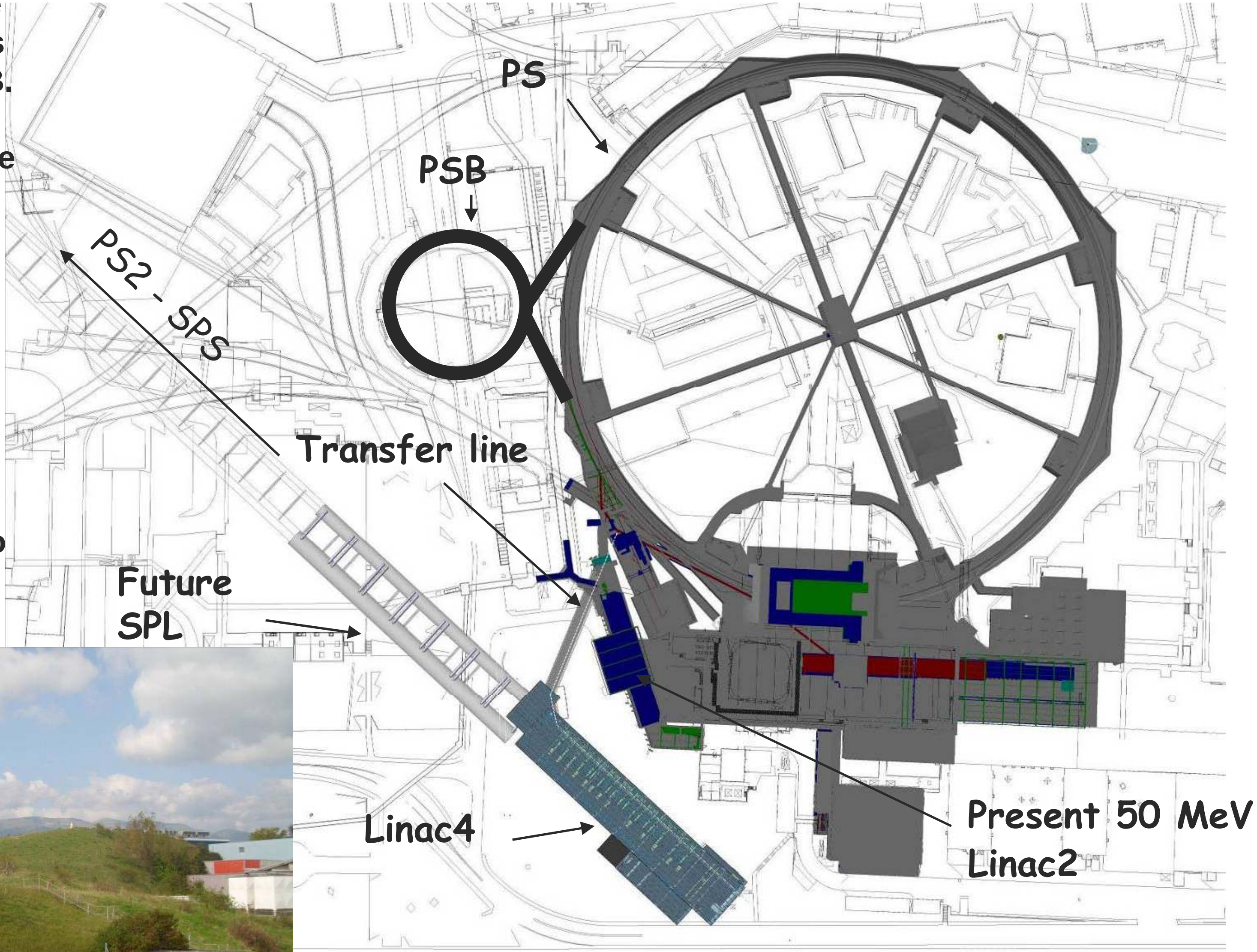
2008: Official start of the project.

Linac4 on the CERN site

Linac4 will replace Linac2 (50 MeV) as injector to the PSB.

It will be built at the place of “Mount Citron”, made in the 50’s with the excavation materials of the PS.

Position and orientation allow a future extension to the SPL.



Linac4: 3 modes of operation

Linac4 is designed to operate in 3 different modes:

1. Injector to PS Booster *(2013-2017?):* 1.1 Hz, 40 mA, 400 μs.
2. Injector to Low Power-SPL *(2018- ?):* 2 Hz, 20 mA, 1.2 ms
   only minor upgrade (few power supplies)
3. Injector to High Power-SPL *(>2020 ?):* 50 Hz, 40 mA, 1.2 ms max.
   important upgrade (RF modulators, power supplies, cooling, etc.)

Main consequences on the design:

1. Shielding dimensioned for the SPL 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).
4. Space provided at the end of the linac for the connection to the SPL

Linac4 Parameters

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	× 10^{14}
Transverse emittance	0.4	π mm mrad

Max. rep. rate for accelerating structures 50 Hz

H^- particles + higher injection energy (160/50 MeV, factor 2 in $\beta\gamma^2$) → same tune shift in PSB with twice the intensity.

Re-use 352 MHz 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.

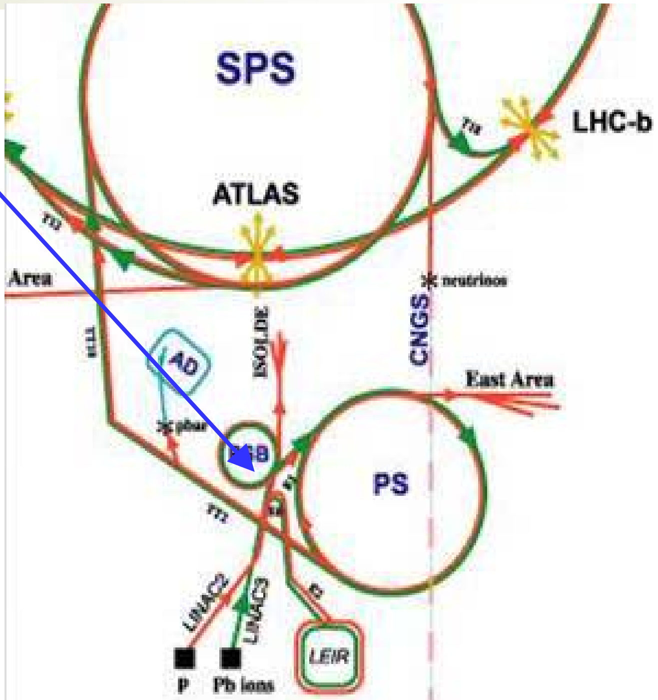
Linac4 for the PS Booster (PSB)

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 (1.2 10^{11} ppb).

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.



☞ Injection energy from 50 to 160 MeV → Increase in $\beta\gamma^2$ by factor 2 → same tune shift at injection ($\Delta Q \propto I/\beta\gamma^2$) with twice the intensity.

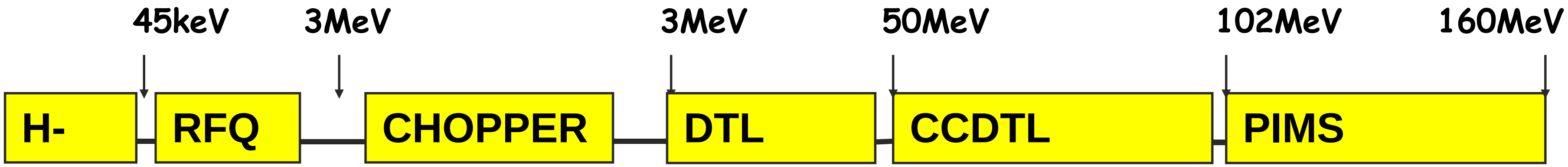
☞ Additional advantages with Linac4:

1. Modern 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, etc.)

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 → uncontrolled beam loss <1 W/m in SPL mode → <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



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

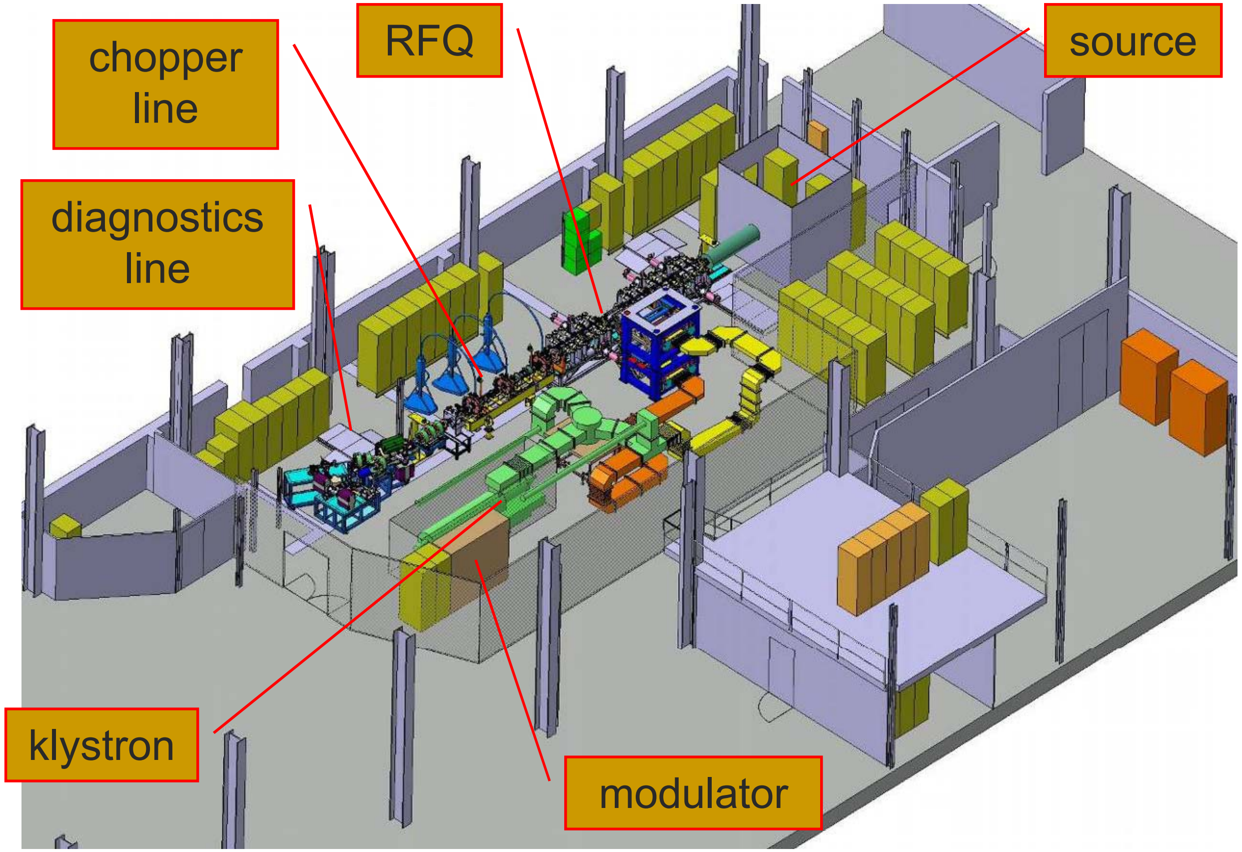
Total Linac4:
80 m, 18 klystrons

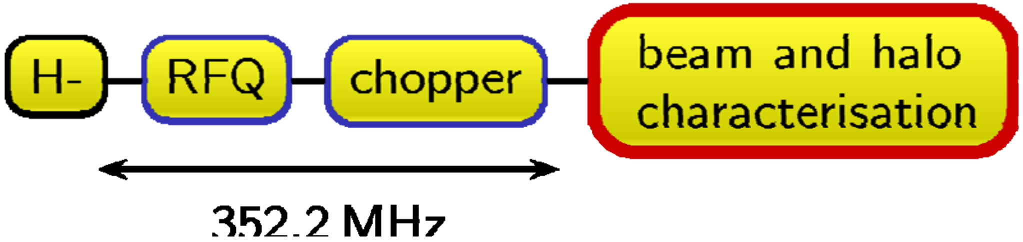
RF Duty cycle:
0.1% phase 1 (Linac4)
3-4% phase 3 (HP-SPL)

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

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

The 3 MeV Test Stand





In construction in the South Hall extension.

- H- source (2008)
- LEBT (2008-09)
- RFQ (February 2010)
- Chopper line (2008)
- Diagnostics line (2010)
- Infrastructure (1 LEP Klystron, pulsed modulator, etc.) - ready

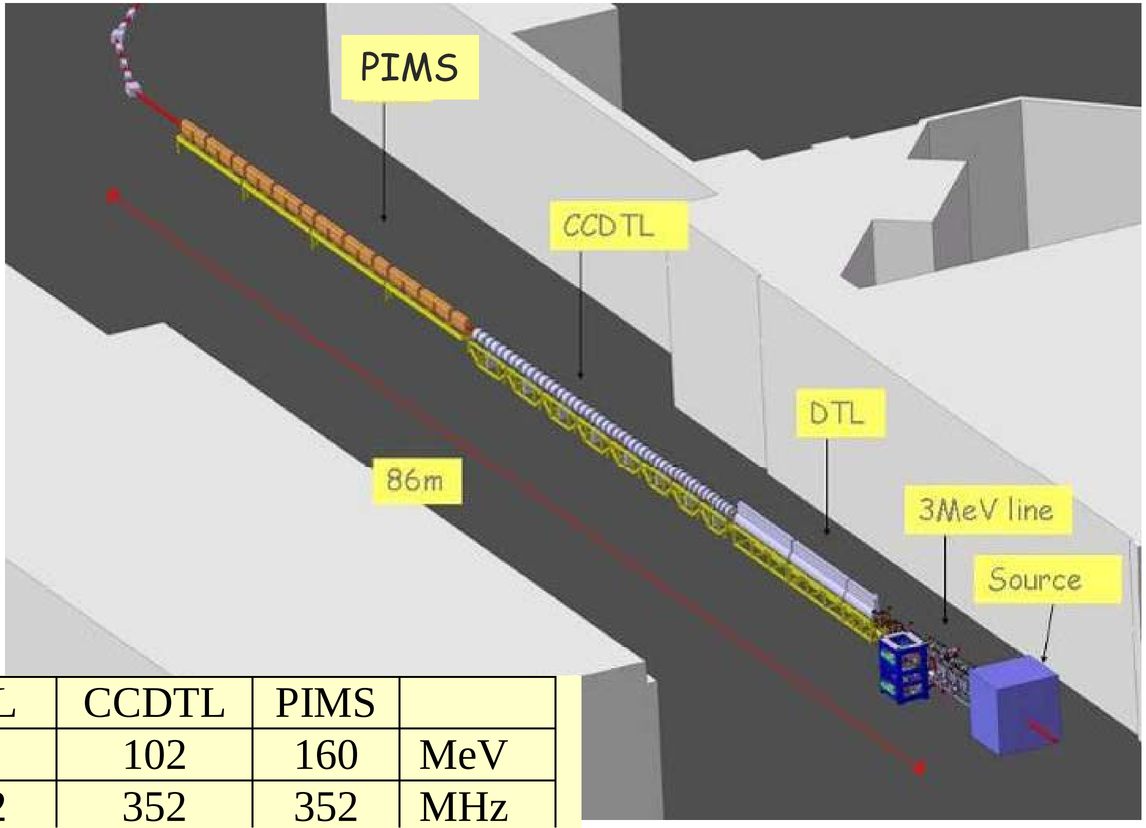
In the front end are concentrated some of the most challenging technologies in linacs, and this is where the beam quality is generated.

Early understanding and optimisation of front-end is fundamental for a linac project.

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

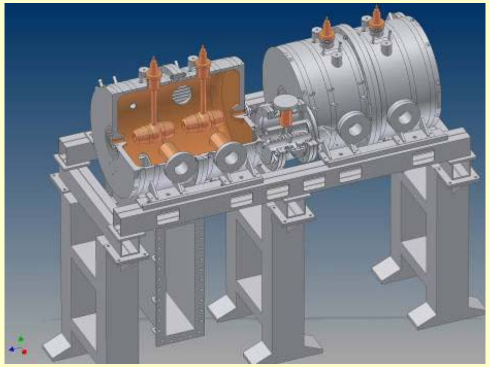
Linac4 accelerating structures

DTL

Conventional DTL structure with:

- ➢ PMQs in vacuum inside drift tube.
- ➢ no drift tube adjustment after installation.

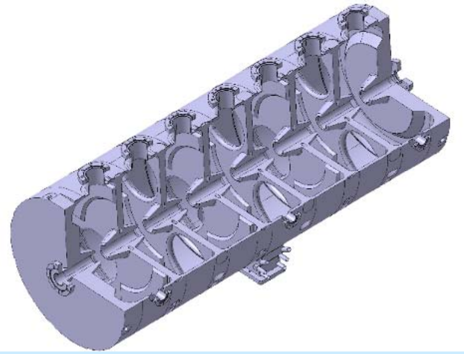
CCDTL



Modules of 3 SDTL-type cavities with 2 drift tubes, coupled by 2 coupling cells.

- ➢ Easy access and alignment of electromagnetic quadrupoles.
- ➢ Relaxed tolerances on drift tube alignment.

PIMS

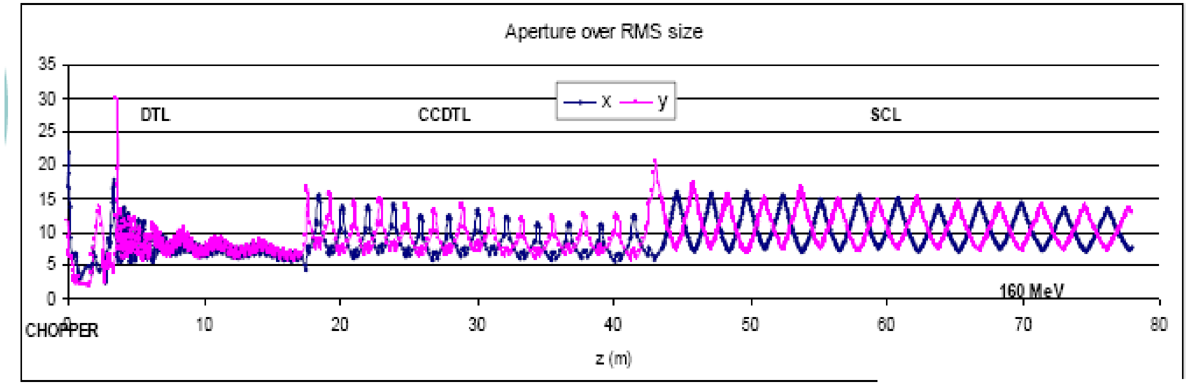


7-cell cavities in π-mode. With respect to the SCL, the PIMS :

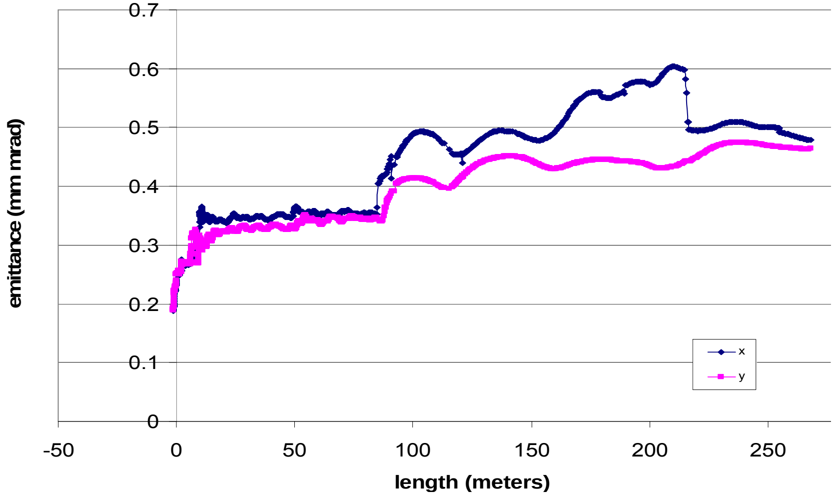
- ➢ has 5 times less cells (less machining time and cost).
- ➢ needs about the same quantity of copper.
- ➢ allows a simpler tuning (7 cells instead of >100, dummy tuners).
- ➢ allows standardisation of the Linac4 frequency to 352 MHz.
- ➢ has only about 12% less shunt impedance.

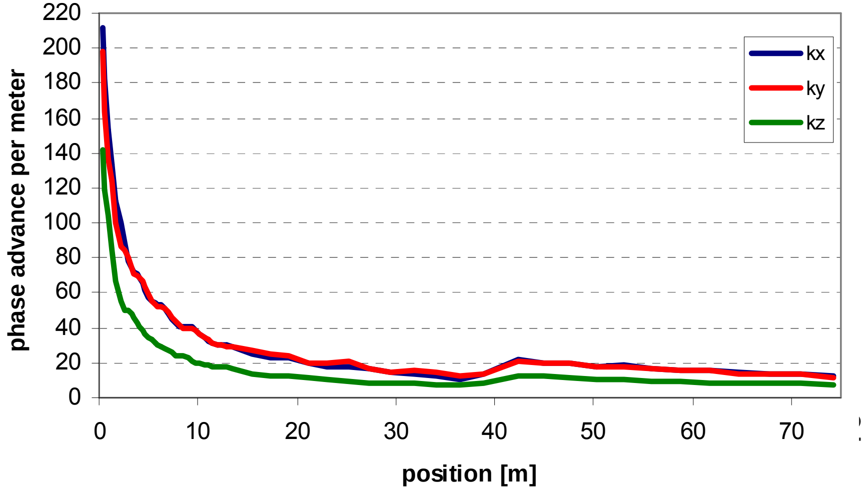
Linac4 Beam Dynamics

Smooth beam dynamics design, to minimise emittance growth and losses at high beam power (<1 W/m):
1. Zero current phase advance <90° (avoid resonances)
2. Longitudinal to transverse phase advance ratio 0.5-0.8 (minimise emittance exchange)
3. Smooth variation of transverse and longitudinal phase advance per meter.
4. Sufficient safety margin between beam radius and aperture (>7 rms)



Integrated simulations with machine errors, alignment errors and steering correction.

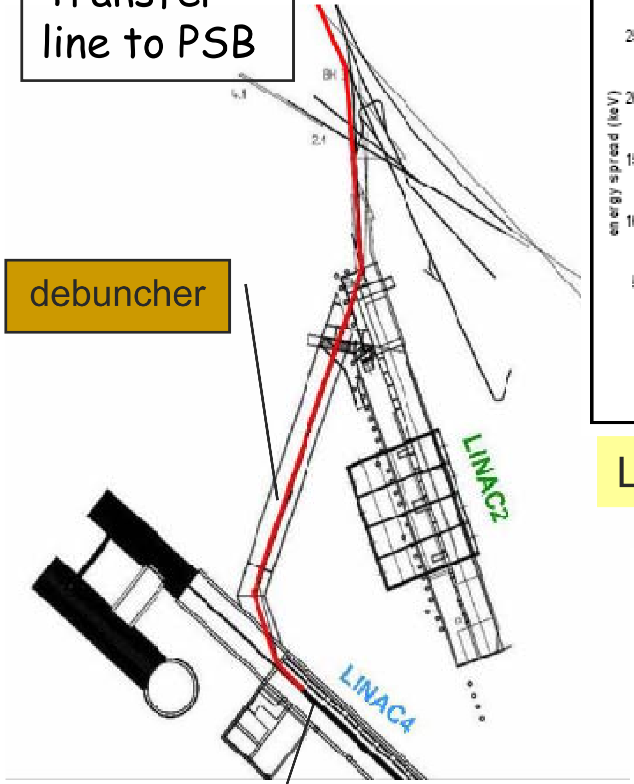




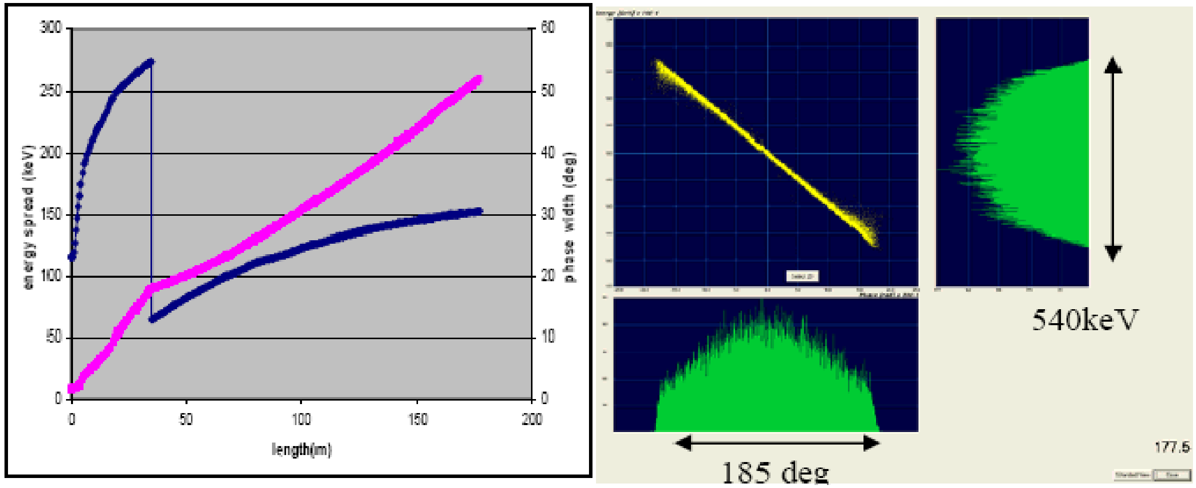
Linac4 Beam – Longitudinal Painting

Transfer line to PSB

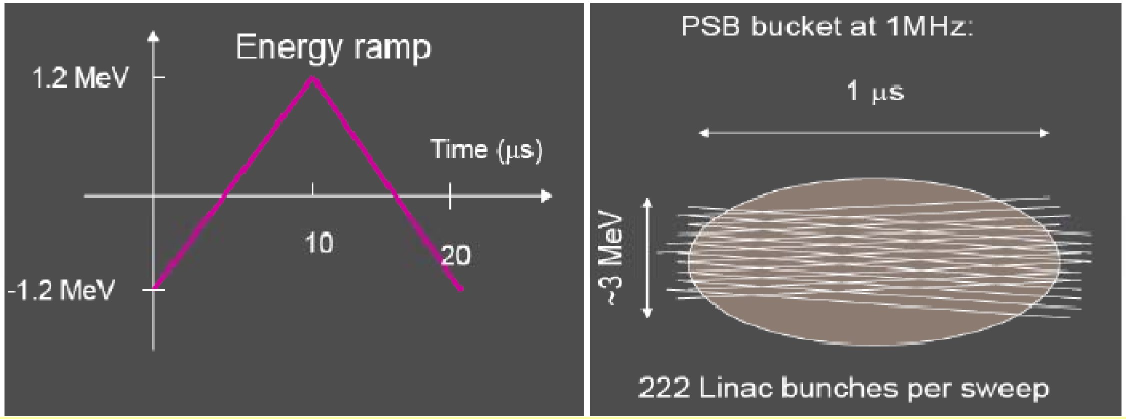
debuncher



Energy modulation with last 2 PIMS cavities

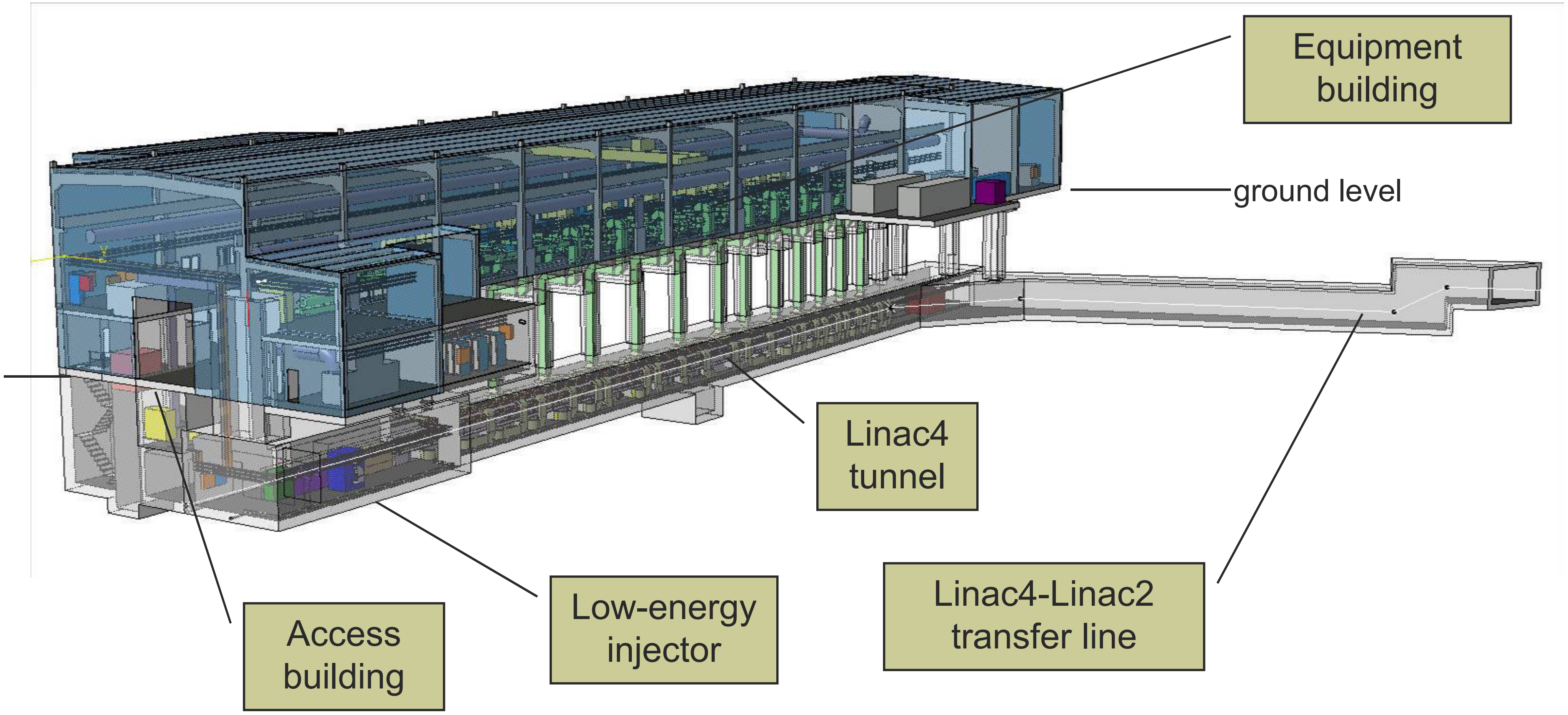


Longitudinal beam parameters along line and at PSB entrance



Painting scheme: linear energy ramp over 10+10 PSB buckets (with low energy chopping limiting sweep to 222 linac bunches)

Linac4 civil engineering



Equipment building

ground level

Linac4 tunnel

Linac4-Linac2 transfer line

Low-energy injector

Access building

Pre-integration May – October 2007
Tendering drawings November 2007 – April 2008
Tendering May 2008, Contract to FC September 2008.
Start of Civil Engineering Works in October 2008.

Linac4 Groundbreaking

16 October 2008, Linac4 Groundbreaking by CERN Director, R. Aymar

Linac4 Groundbreaking

Linac4 Groundbreaking – The team

Linac4 Work Breakdown Structure

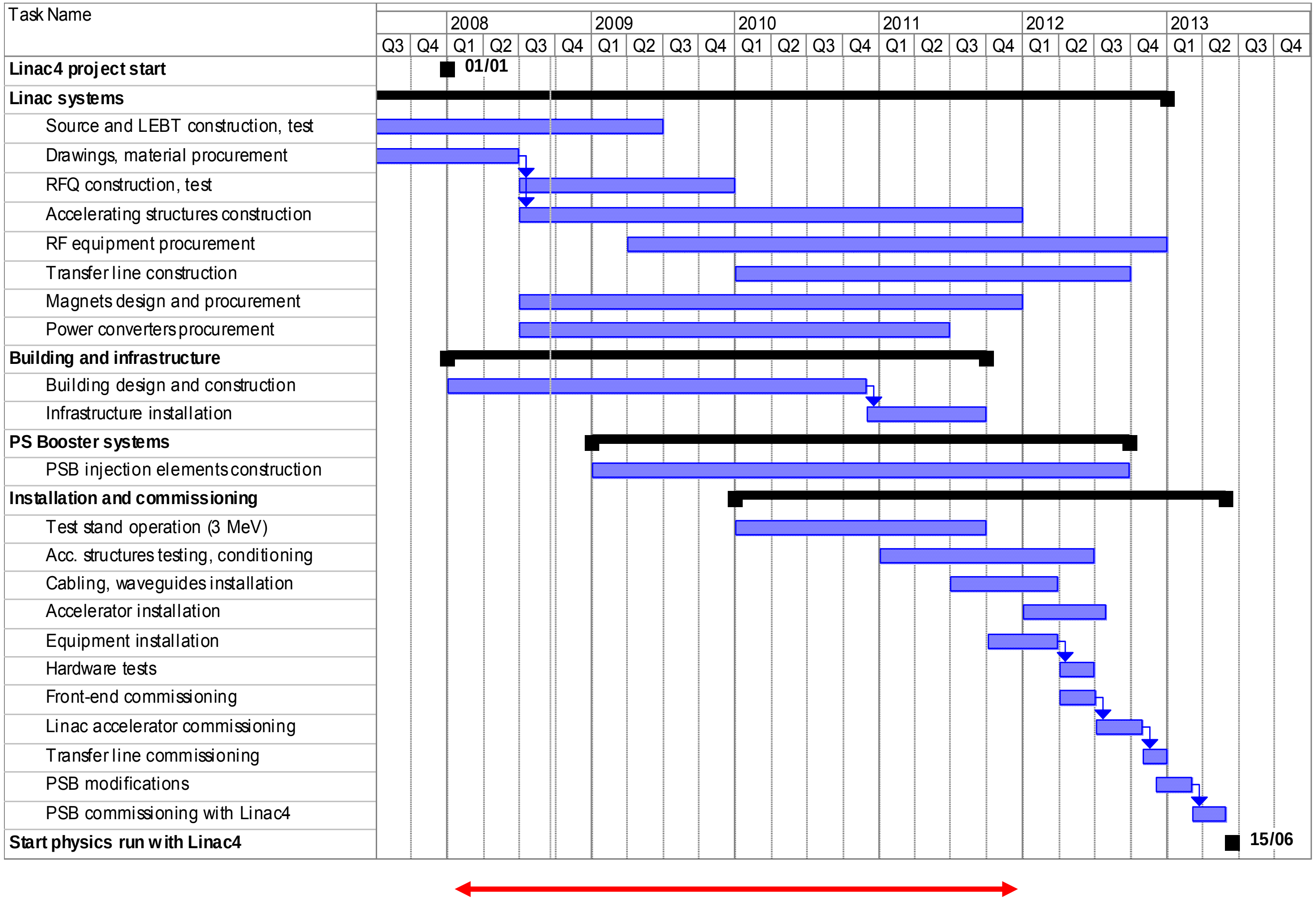
LINAC4 WORK BREAKDOWN STRUCTURE

L I N A C 4

- **1. Management,** *M. Vretenar + core team*
- **2. Linac Systems**
  - **2.1 Ion Source and LEBT,** *R. Scrivens, AB/ABP*
  - **2.2 Radio Frequency Quadrupole**
    - **2.2.1 RFQ Funct. design, Commissioning,** *C. Rossi, AB/RF*
    - **2.9.2 RFQ Mech. design, Fabrication,** *S. Mathot,TS/MME*
  - **2.3 Chopper Line,** *A. Lombardi, AB/ABP*
  - **2.4 Accelerating Structures,** *F. Gerigk, AB/RF*
  - **2.5 Linac Beam Dynamics,** *A. Lombardi, AB/ABP*
  - **2.6 Radio Frequency Systems**
    - **2.6.1 Low Level RF Systems,** *P. Baudrenghien, AB/RF*
    - **2.6.2 High Power RF Systems,** *O. Brunner, AB/RF*
    - **2.6.3 Slow Tuning and Interlocks,** *L..Arnaudon, AB/RF*
    - **2.6.4 Tube Amplifiers,** *J. Broere, AB/RF*
  - **2.7 Beam Instrumentation,** *U. Raich, AB/BI*
  - **2.8 Transfer Line,** *S. Maury, AB/ABP*
  - **2.9 Magnets**
    - **2.9.1 Magnet Design and Procurement,** *T. Zickler, AT/MCS*
    - **2.9.2 Magnetic Measurements,** *M. Buzio, AT/MEI*
  - **2.10 Power Converters,** *C. De Almeida, AB/PO*
  - **2.11 Vacuum Systems,** *G. Vandoni, AT/VAC*
  - **2.12 Control Systems,** *J. Serrano, AB/CO*
  - **2.13 Beam Intercepting devices,** *Y. Kadi, AB/ATB*
- **3. Booster Systems**
  - **3.1 Booster Injection Mod.,** *W. Weterings, AB/BT*
  - **3.2 PSB Beam Dynamics,** *C. Carli, AB/ABP*
- **4. Installation commiss.**
  - **4.1 Test Stand Operation,** *C. Rossi, AB/RF*
  - **4.2 Transport and Installation,** *S. Prodon, TS/IC*
  - **4.3 Survey,** *M. Jones, TS/SU*
  - **4.4 Linac Commissioning,** *A. Lombardi, AB/ABP*
  - **4.5 PS Booster Commissioning**
    - **4.5.1 PSB Commissioning to nominal,** *K..Hanke, AB/OP*
    - **4.5.2 PSB Commissioning to ultimate,** *C. Carli, AB/ABP*
- **5. Building, Infrastruct.**
  - **5.1 Building Design, Construction,** *N. Lopez, TS/CE*
  - **5.2 Cooling and Ventilation,** *Y. Body, TS/CV*
  - **5.3 Electrical Systems,** *J. Pierlot, TS/EL*
  - **5.4 Access Systems,** *D. Chapuis, TS/CSE*

Total of 30 Workpackages

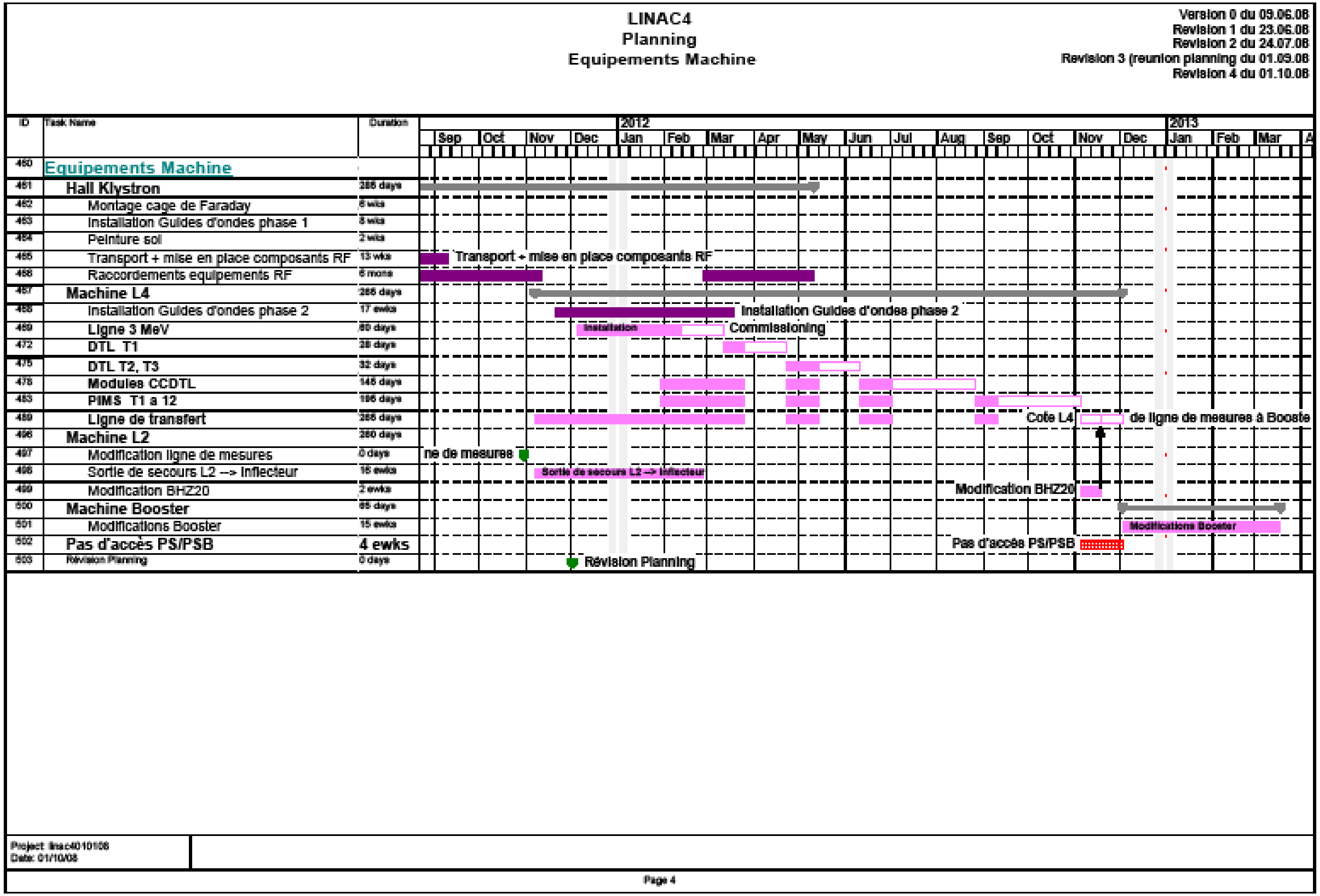
Linac4 Master Plan



White Paper

- ✓ End CE works: December 2010
- ✓ Installation: 2011
- ✓ Linac commissioning: 2012
- ✓ Modifications PSB: shut-down 2012/13 (7.5 months)
- ✓ Beam from PSB: 15.6.2013

Installation and commissioning



LINAC4
Planning
Equipements Machine

Version 0 du 09.06.08
Revision 1 du 23.06.08
Revision 2 du 24.07.08
Revision 3 (reunion planning du 01.09.08
Revision 4 du 01.10.08

ID	Task Name	Duration
460	Equipements Machine	
461	**Hall Klystron**	288 days
462	Montage cage de Faraday	6 wks
463	Installation Guides d'ondes phase 1	8 wks
464	Peinture sol	2 wks
465	Transport + mise en place composants RF	13 wks
466	Raccordements equipements RF	6 mons
467	**Machine L4**	288 days
468	Installation Guides d'ondes phase 2	17 ewks
469	**Ligne 3 MeV**	80 days
472	**DTL T1**	28 days
475	**DTL T2, T3**	32 days
476	**Modules CCDTL**	148 days
483	**PIMS T1 a 12**	186 days
489	**Ligne de transfert**	288 days
496	**Machine L2**	280 days
497	Modification ligne de mesures	0 days
498	Sortie de secours L2 --> Inflecteur	16 ewks
499	Modification BHZ20	2 ewks
500	**Machine Booster**	65 days
501	Modifications Booster	15 ewks
502	**Pas d'accès PS/PSB**	4 ewks
503	Révision Planning	0 days

Project: linac4010108
Date: 01/10/08

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Linac4 Status (11/2008)

- Civil Engineering works started 22.10.2008, delivery of building end 2010.
- Safety File submitted to CERN Safety Commission in June 2008. Building approved.

- Ion source almost completed, first beam tests end 2008.
- 3 MeV Test Stand infrastructure completed.
- Prototype modulator tested with LEP klystron in pulsed mode.
- Prototypes of accelerating structures tested (CCDTL), being tested (DTL), starting construction (PIMS). Material being ordered, construction of DTL and CCDTL will start in 2009.
- Started preparation for large contracts (klystrons, modulators, magnets,…).

- Detailed descriptions of Workpackages in preparation, project baseline will be frozen at end 2008.
- Advanced negotiations for in-kind contributions with France, Russia (via the ISTC Organisation), Poland, Spain (via ESS-Bilbao), India, Pakistan, Saudi Arabia.