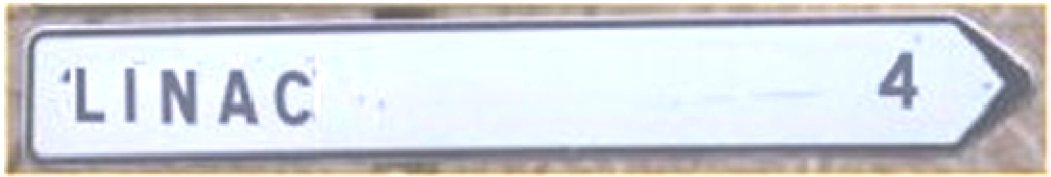
Linac4

M. Vretenar for the Linac4 team



10.07.2009

Motivations for new CERN injectors

1. Prepare for a progressive increase in LHC luminosity *by removing the main limitations coming from the injectors*.

2. Improve reliability of LHC injector chain *replacing ageing accelerators (between 31 and 50 year old) operating far beyond initial parameters*.

⇒ need for new accelerators designed for the sLHC

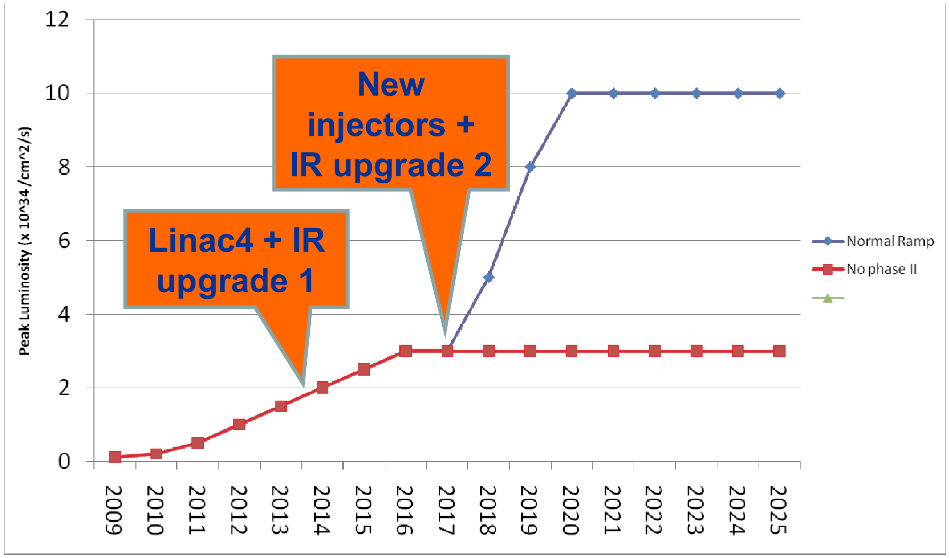
Main performance limitation:

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

⇒ need to increase the injection energy in the synchrotrons.

- Injection energy in the PSB from 50 to 160 MeV
- New PS (PS2) for maximum sLHC beam.
- Injection energy in the SPS from 25 to 50 GeV.

LHC Peak Luminosity – projection 2009-25 (L. Evans)



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

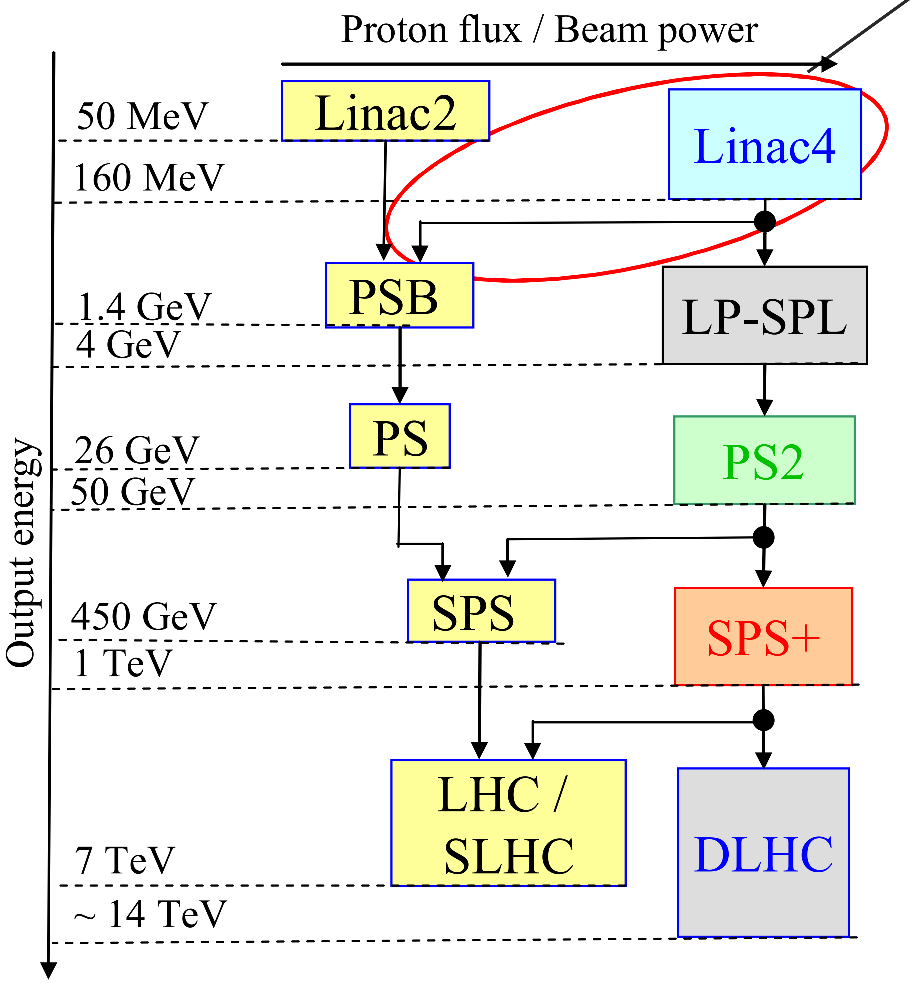
with N_b : number of protons/bunch

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

R : mean radius of the accelerator

$\beta\gamma$: classical relativistic parameters

The Injector Complex Upgrade



The Linac4 Project

Linac4: H- Linac
(160 MeV)
(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)

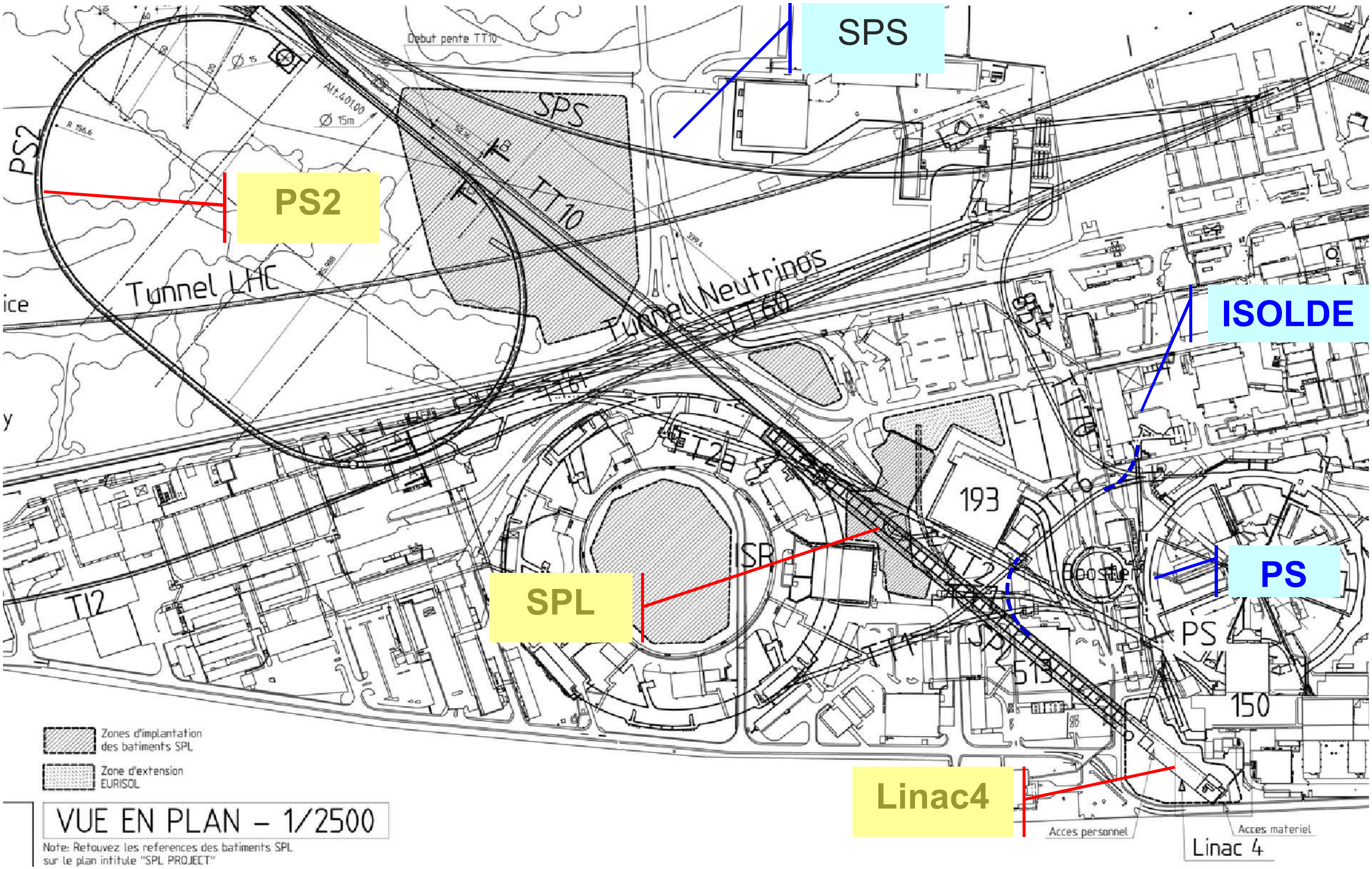
Stage 1: Linac4
- construction 2008 – 2014

Stage 2: PS2 and SPL: preparation of Conceptual Design Reports for
- **project approval mid 2012**
- **start of construction begin 2013**

Linac4: in a <u>first stage</u> will replace Linac2 as injector to the PSB
in a <u>second stage</u> will inject into the SPL, replacing the PSB

Linac4 because the 4th linear accelerator for ions to be built at CERN

Layout on the CERN site



Linac4 civil engineering

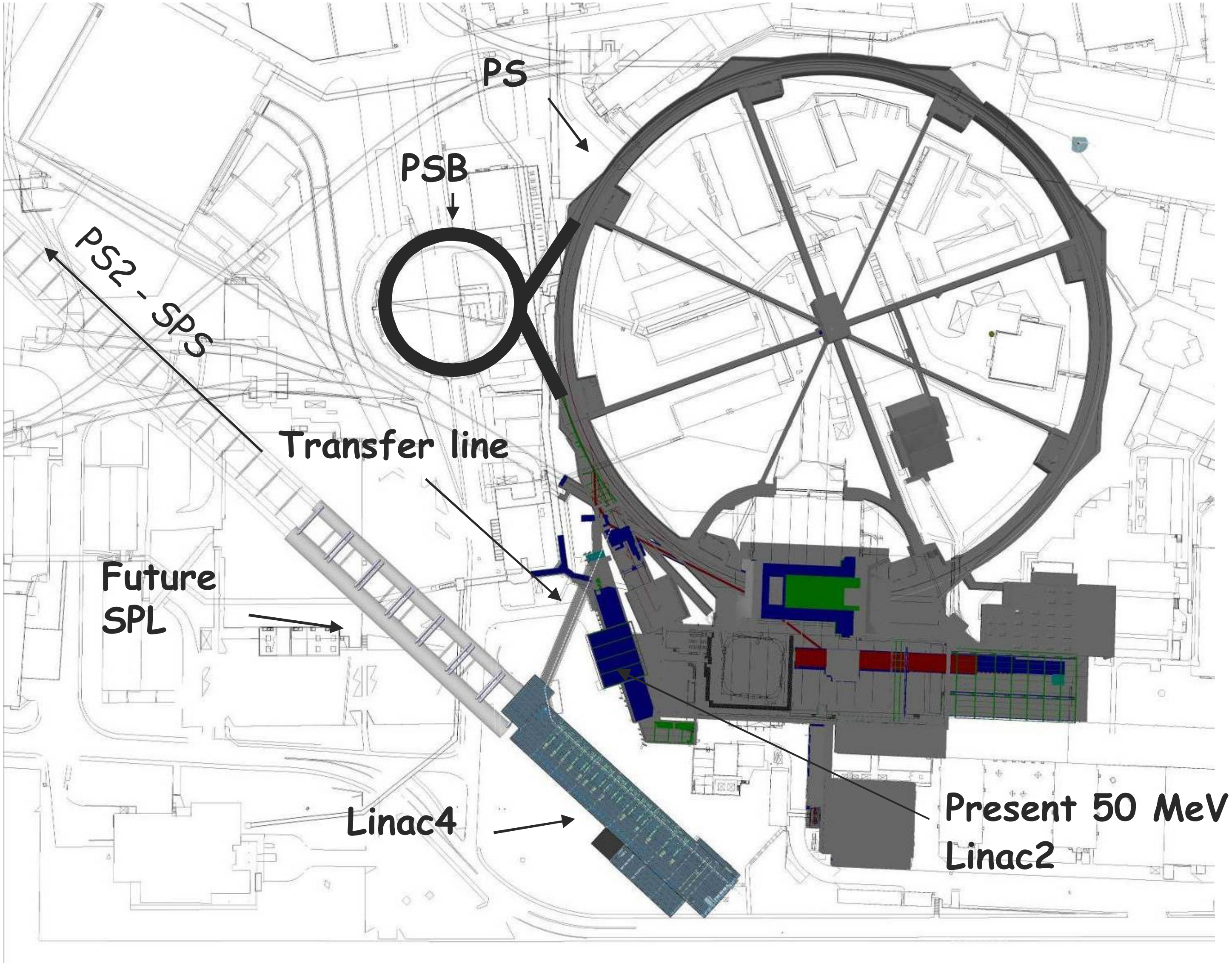
Main requirements:

Length ~100m

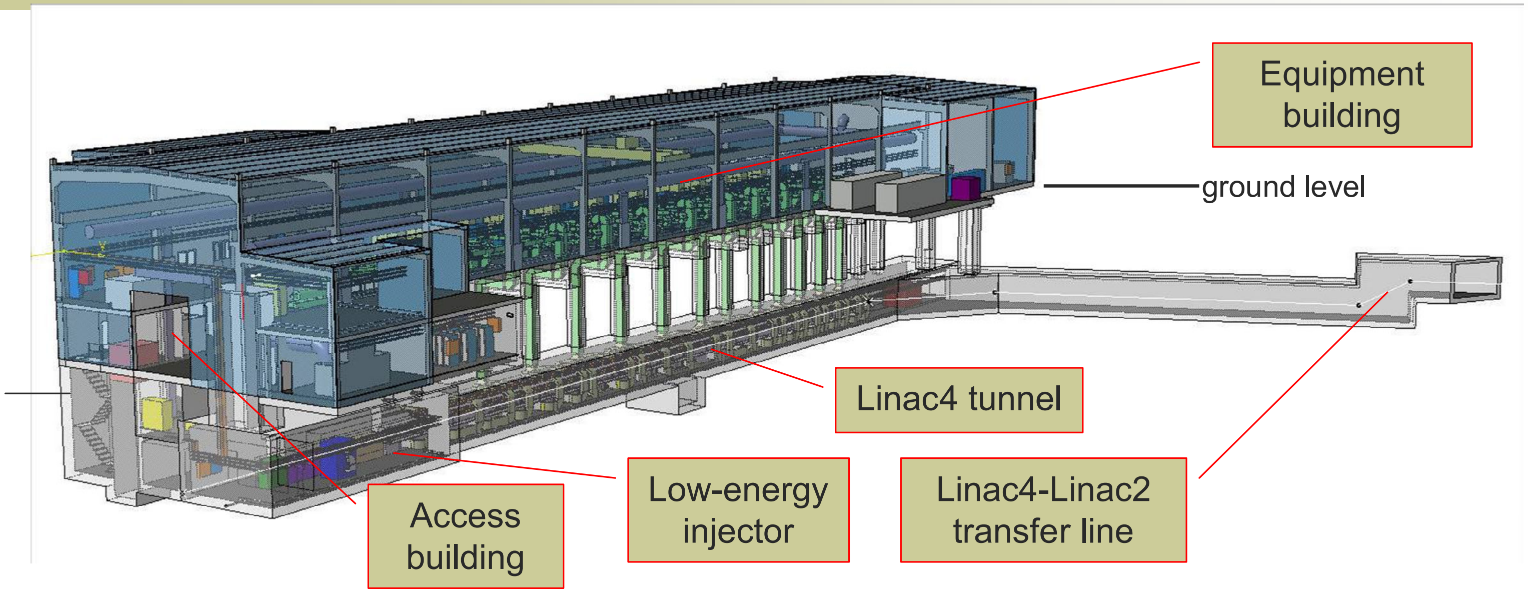
- Connection with the PSB
- Possible extension to the future SPL

Preferred location ("Mount Citron"):

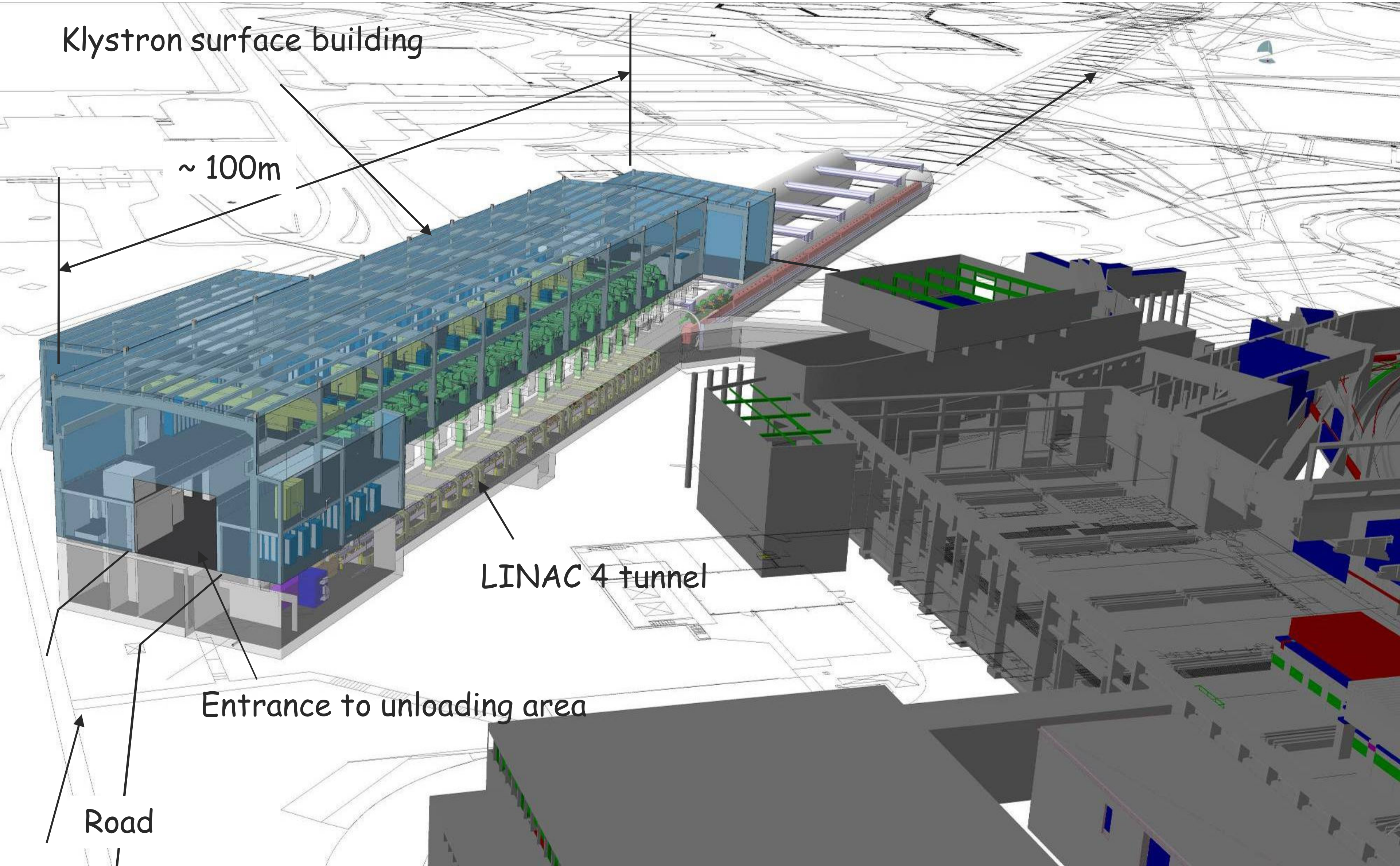
- Correct size (~100m x 30m).
- Easy connection to existing Linac2-PSB line.
- Orientation towards SPL – PS2.
- Natural shielding: underground, but at PSB level.
- No interference with Linac2 and PSB operation during construction and commissioning.



Linac4 civil engineering



Groundbreaking 16.10.2008, end of Civil Engineering works December 2010


Klystron surface building
~ 100m
LINAC 4 tunnel
Entrance to unloading area
Road

Linac4 construction site – 5.5.2009

Linac4 tunnel ("cut and cover" excavation) seen from high-energy side.

Final concrete works starting at low-energy side, excavation proceeding at high energy side.

Tunnel level -12 m, length 100 m.

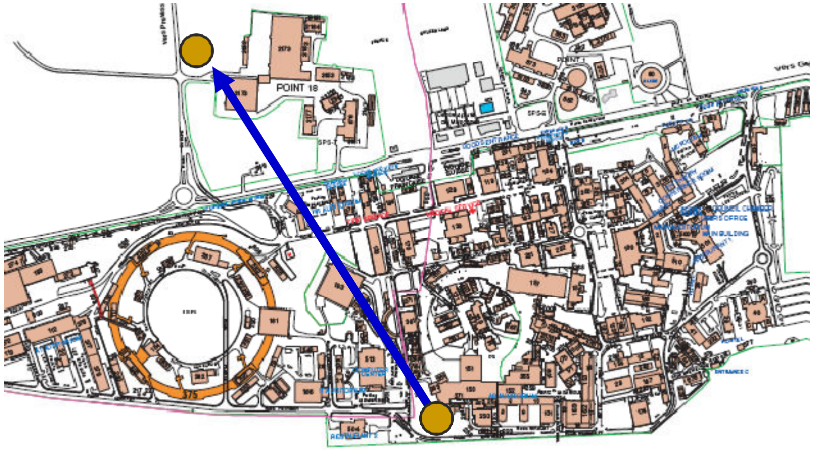
Delivery of tunnel and surface equipment building end of 2010.

PSB and SPL connection area

High-energy side of Linac4 tunnel, with beam dump chamber and connecting tunnel to Linac2 line.

Moving mountains…

“Mount Citron” (40’000 m3) has been displaced by 900 meters, through the CERN tunnel and across the Swiss-French border.



Under the L2-PSB technical gallery

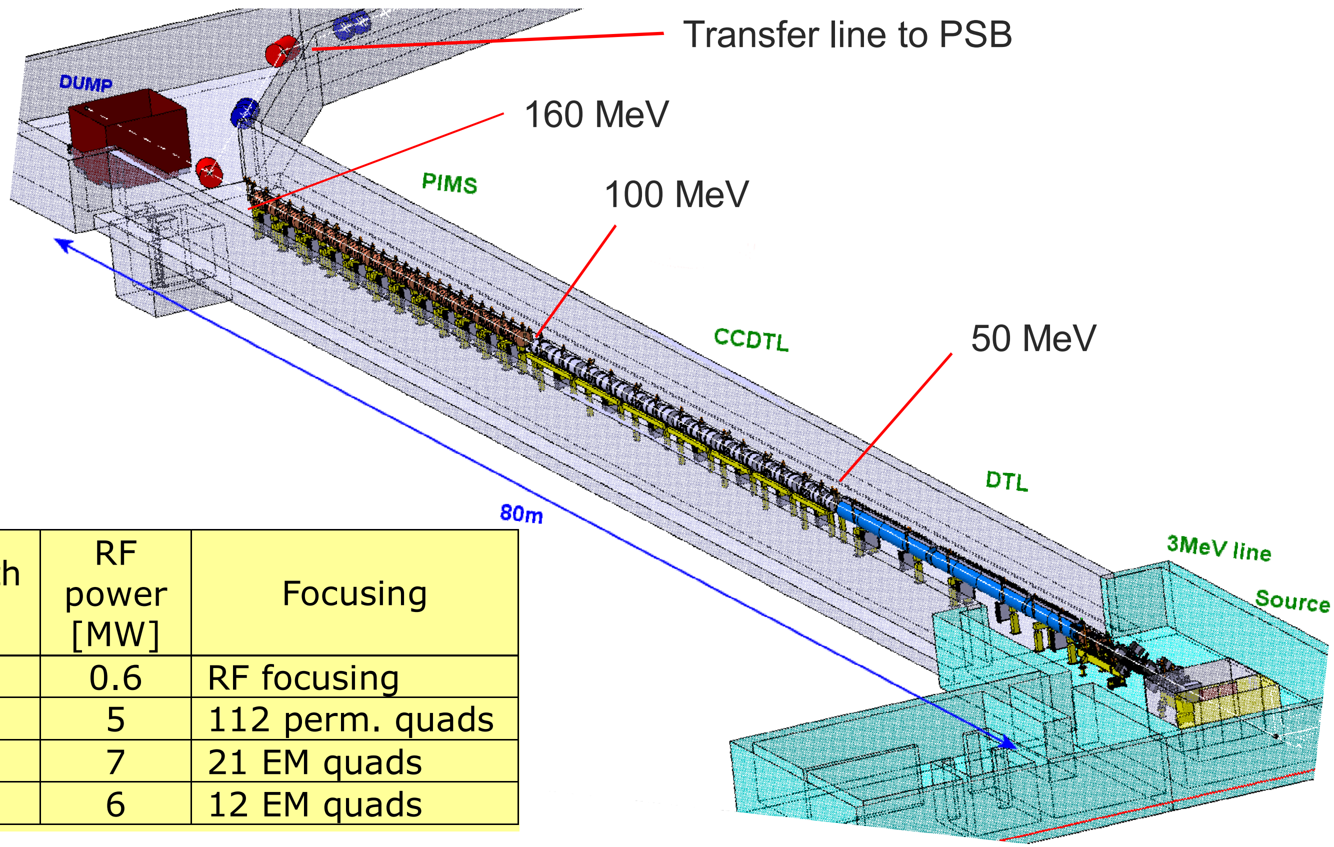
Excavation under the technical gallery PSB-Linac2, completed 25-29.5.2009

The last wall…

Wall of Linac2 building at connection point, 03.06.2009

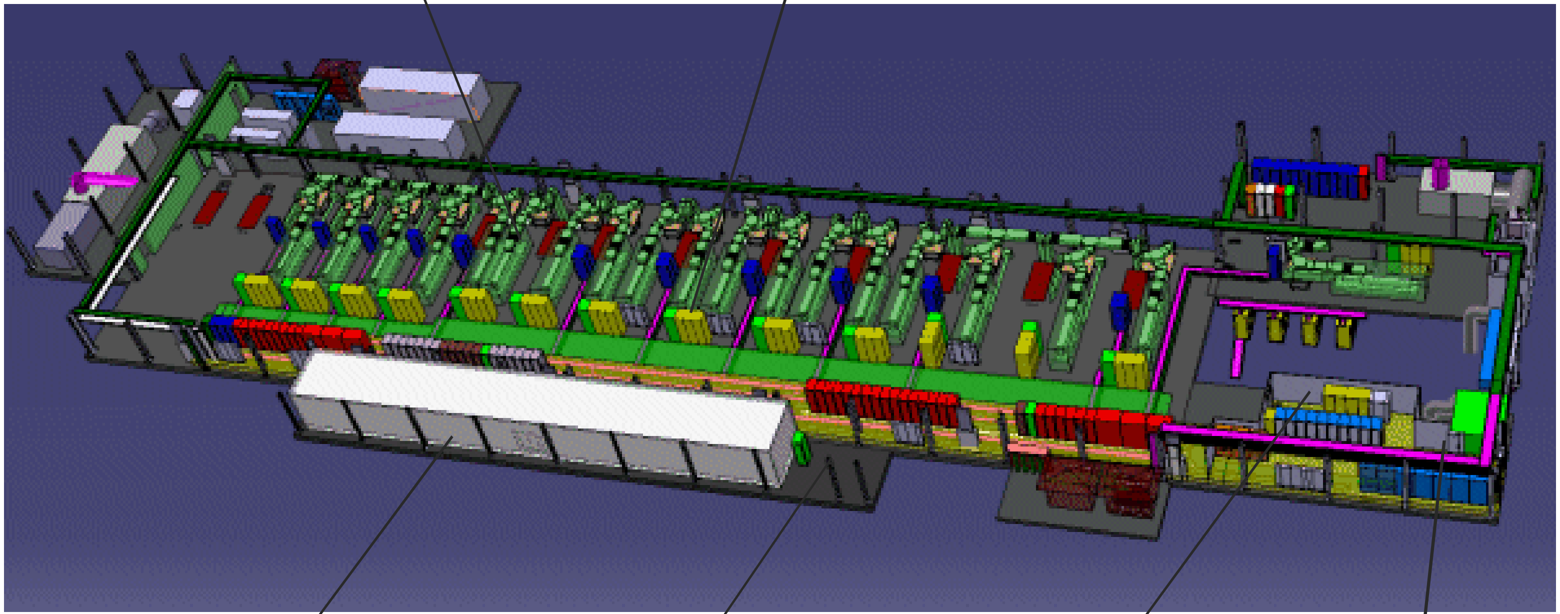
Linac4 layout

- Linac4 is a normal-conducting H^- linear accelerator at 160 MeV energy, made of 4 types of accelerating structures at 352 MHz, each matched to the increasing beam energy. The linac is terminated in a beam dump for beam setting-up (to be displaced for SPL). A switching magnet sends the beam to a transfer line connected to the present Linac2 to PSB line.
- The Linac4 project includes important modifications to the PSB injection region (higher injection energy, H- stripping).

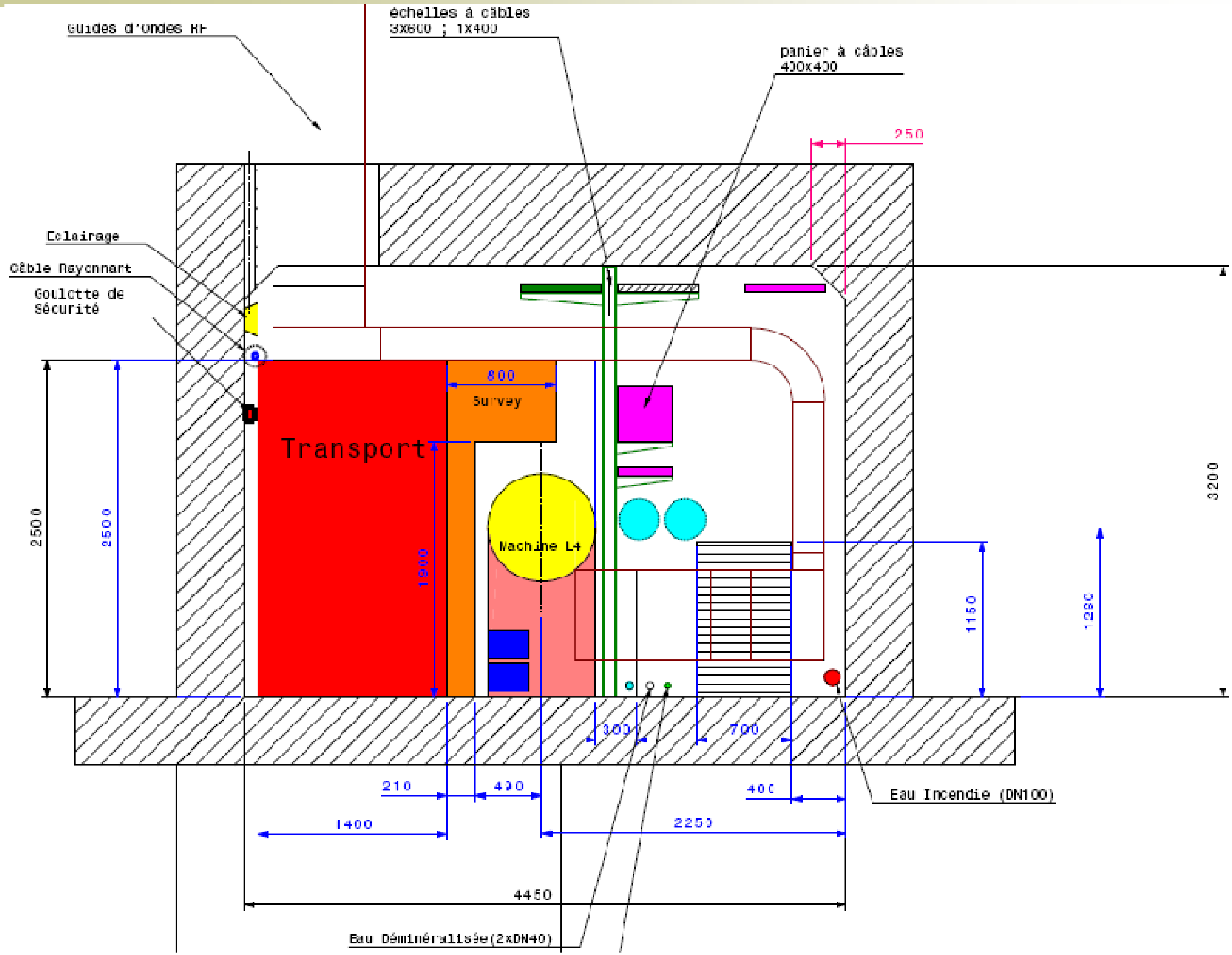


	Energy [MeV]	Length [m]	RF power [MW]	Focusing
RFQ	0.045 – 3	3	0.6	RF focusing
DTL	3 – 50	19	5	112 perm. quads
CCDTL	50 – 102	25	7	21 EM quads
PIMS	102 – 160	22	6	12 EM quads

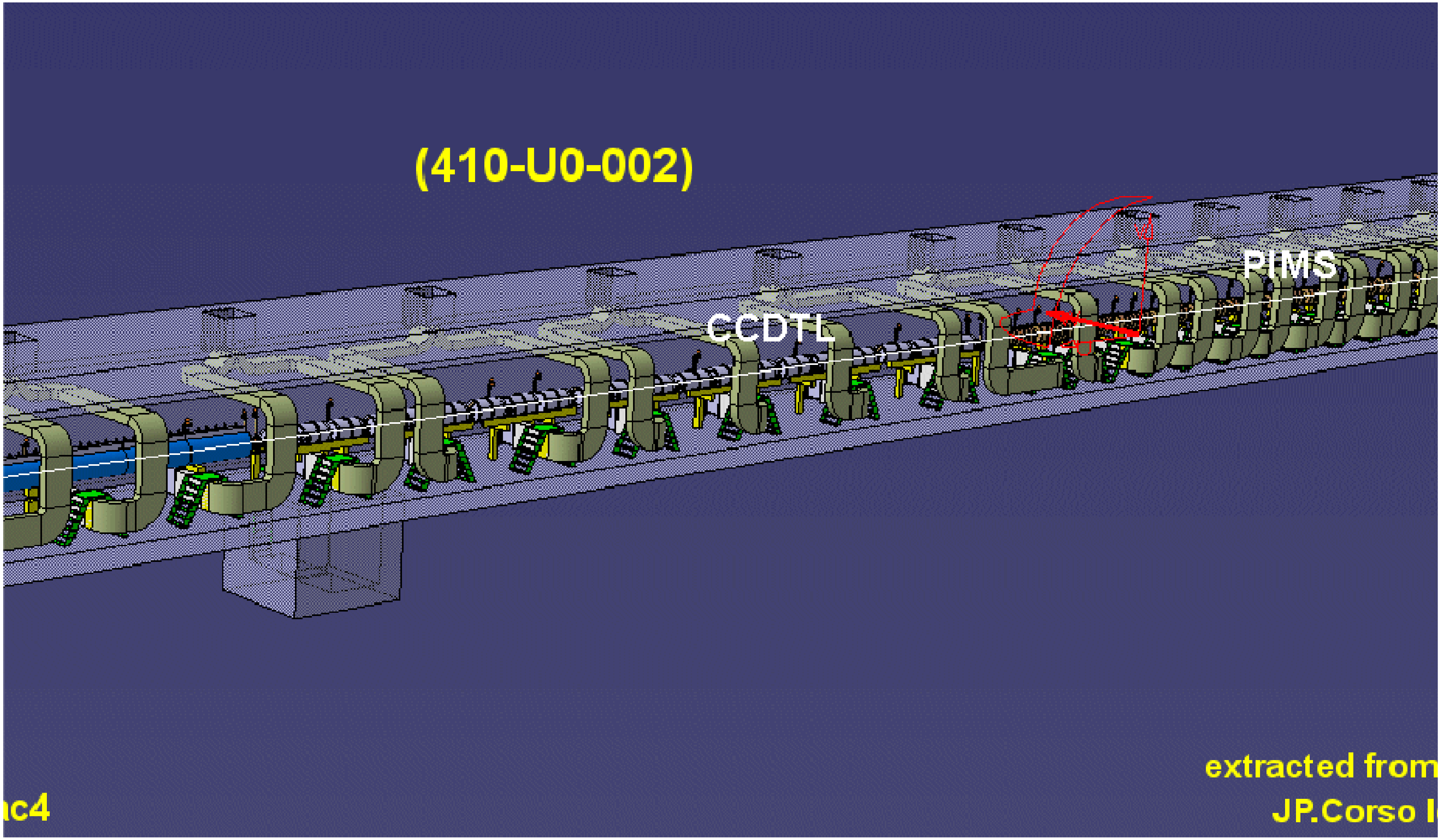
Linac4 – Equipment building



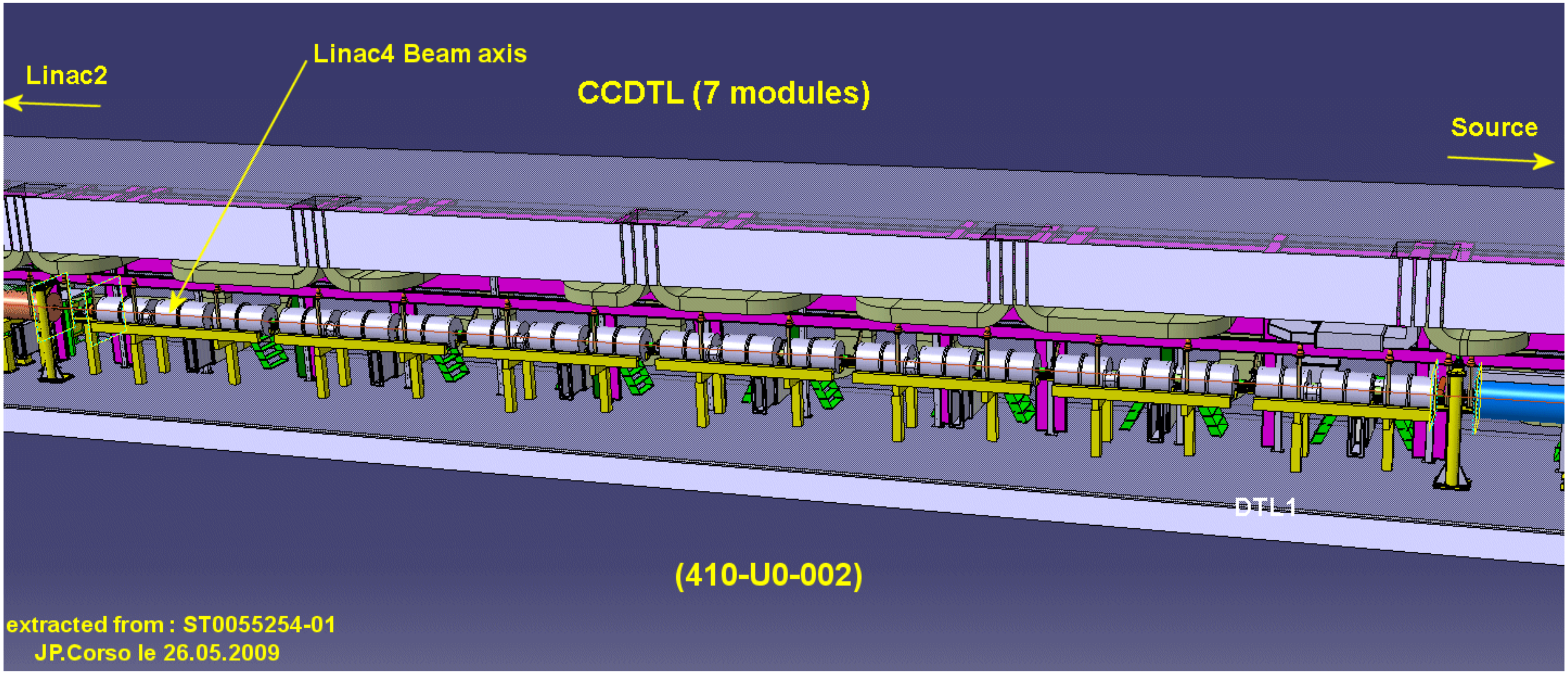
Linac4 – tunnel cross section



CCDTL in Linac4 tunnel - 1



CCDTL in Linac4 tunnel - 2



Linac4: 3 modes of operation

Linac4 is designed to operate in 3 different modes:

1. Injector to PS Booster (2014 - 2019): 1.1 Hz, 40 mA, 400 μs.
2. Injector to Low Power-SPL (2020 - …): 2 Hz, 20 mA, 1.2 ms
   only minor upgrades
3. Injector to High Power-SPL (?): 50 Hz, 40 mA, 1.2 ms max.
   major 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 (low additional cost, operational margin).
3. Power supplies, electronics and infrastructure (water, electricity) dimensioned 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	$\times 10^{14}$
Transverse emittance	0.4	π mm mrad

Max. rep. rate for accelerating structures 50 Hz

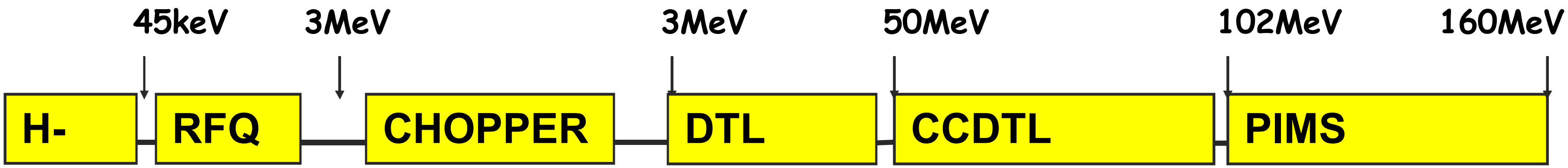
H^- particles + higher injection energy (160/50 MeV, factor 2 in $\beta\gamma^2$) $\rightarrow$ same tune shift in PSB with twice the intensity.

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 Layout



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

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)

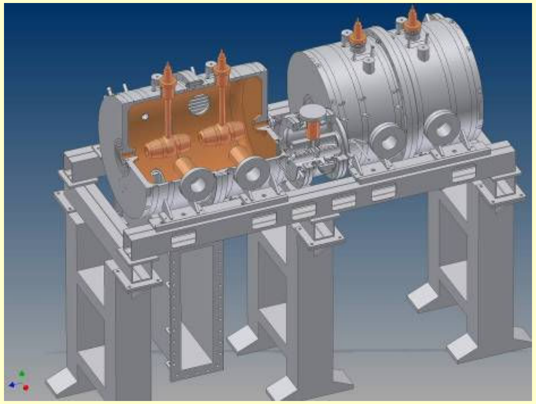
Linac4 accelerating structures

DTL, 3 – 50 MeV

Drift Tube Linac (3 tanks)

Prototype built, under testing.
Costruction starts in 2009

CCDTL, 50 – 100 MeV

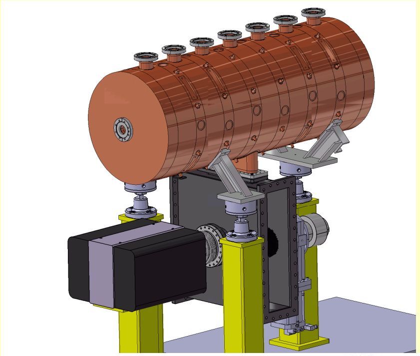


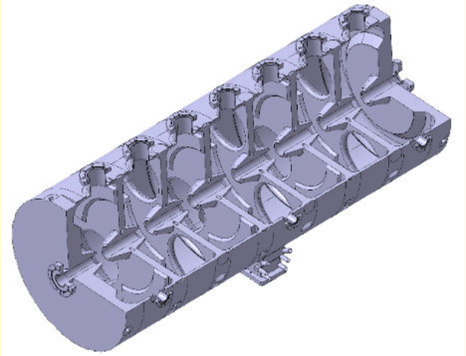
Cell-Coupled Drift Tube Linac (7 modules)

Modules of 3 DTL-type cavities (2 drift tubes), connected by coupling cells.

Prototypes built and tested, construction starts in 2009

PIMS, 100 – 160 MeV

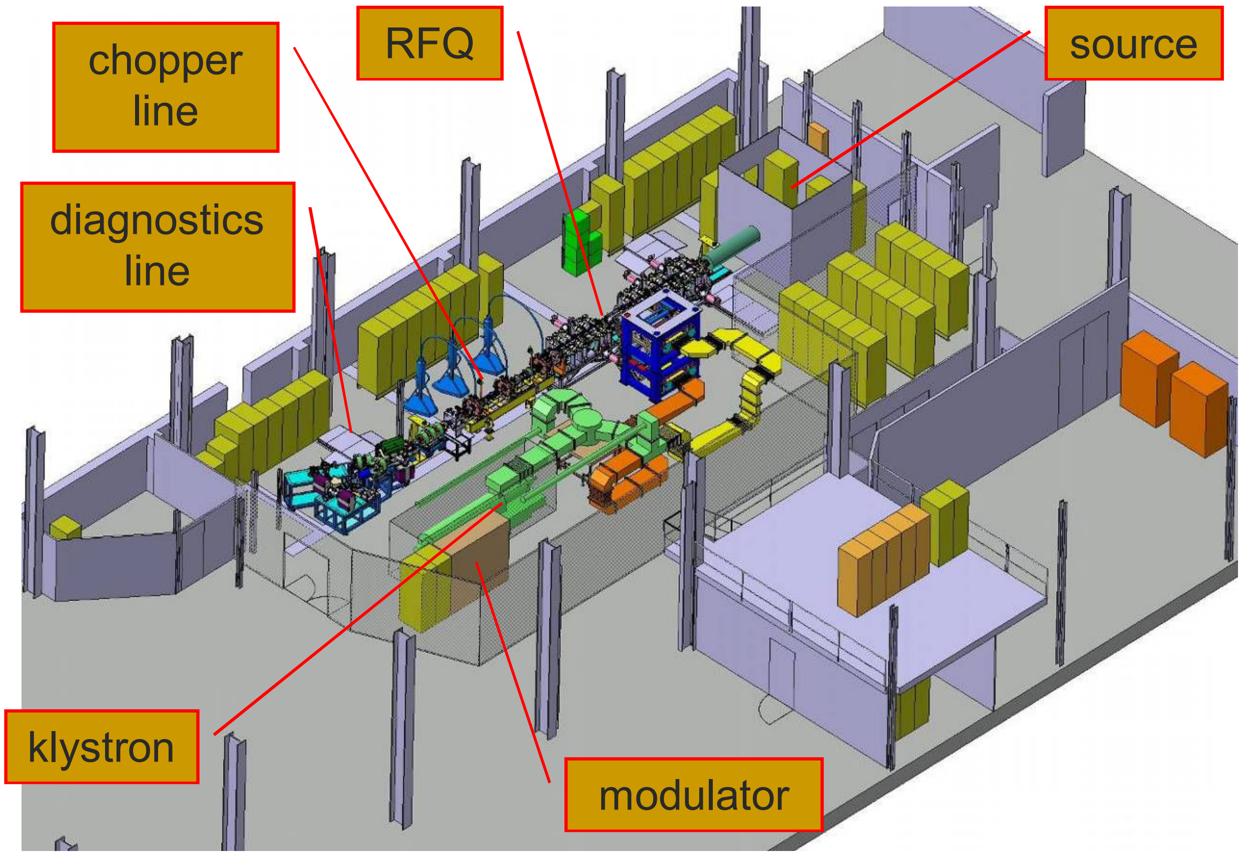




7-cell cavities in p-mode (12 cavities)

Prototype in construction

The 3 MeV Test Stand

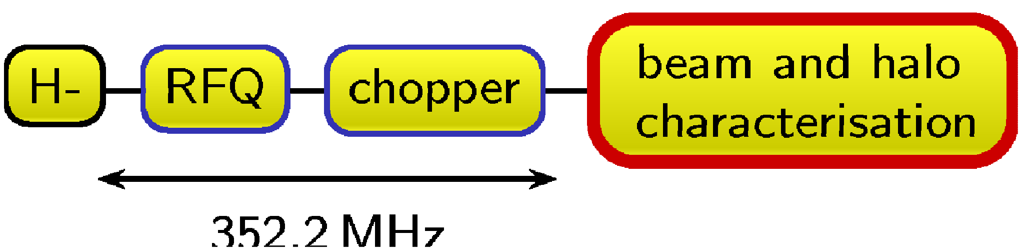


In construction in the South Hall extension.

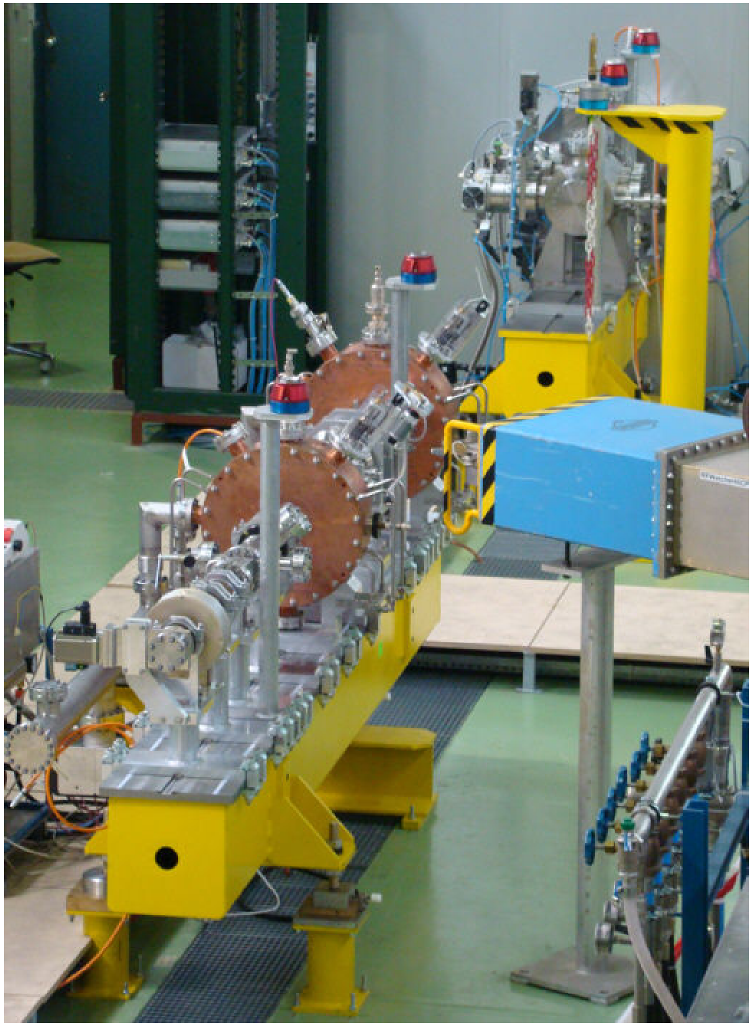
- H- source (2008)
- LEBT (2008-09)
- RFQ (February 2010)
- Chopper line (2008)
- Diagnostics line (2010)
- Infrastructure (1 LEP Klystron, pulsed modulator, etc.) - ready

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.



3 MeV Test Stand – 02/2009



Chopper line assembled

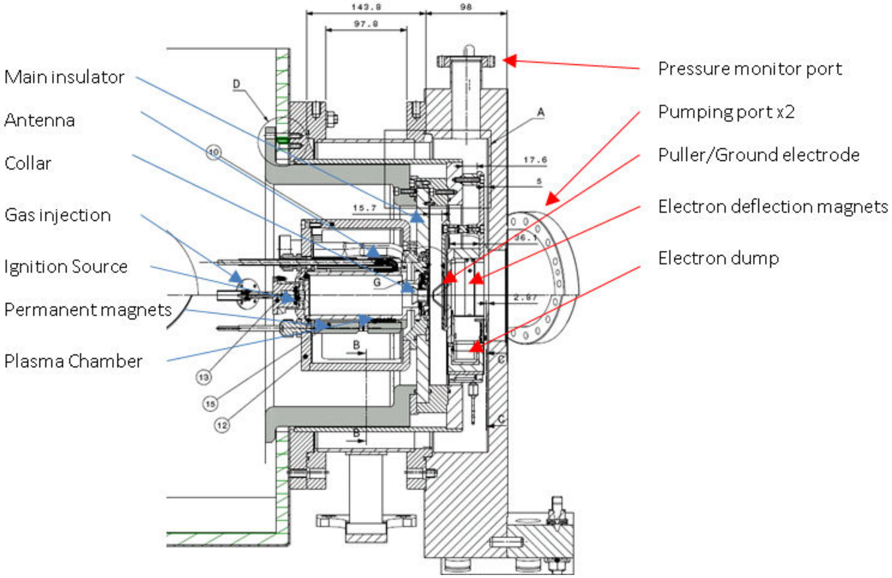
LEP-type klystron and prototype modulator under test

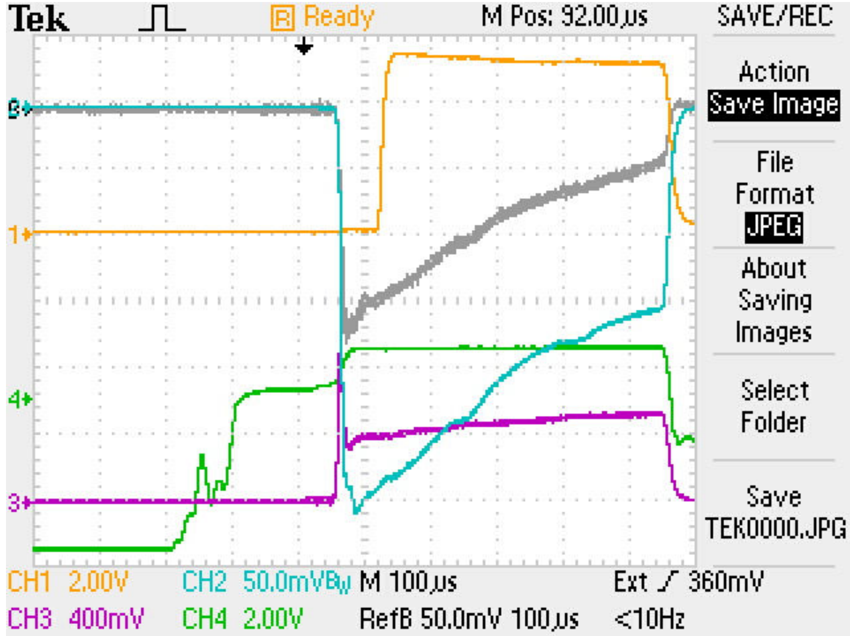
1st negative ion beam – July 2, 2009

LINAC4 RF ION SOURCE

6 mA of negative ions
measured at the Faraday cup

15 kV (nominal 45 kV)
Low RF power



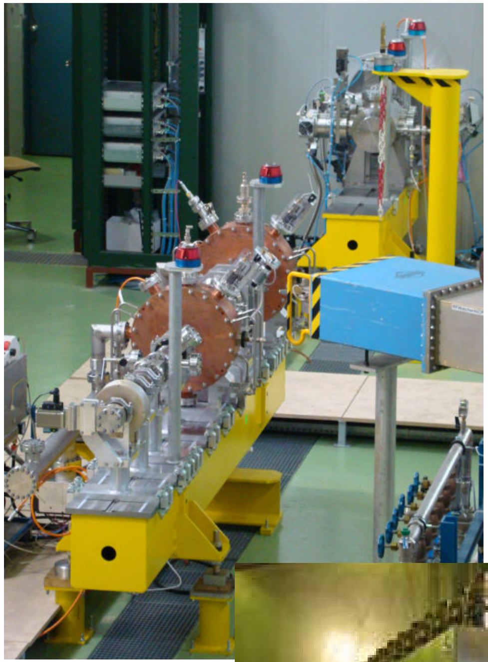


1. Orange=light from RF plasma
2. Blue= Faraday Cup Signal (into 50 Ohms).
   (1mA per division)

Grey= Faraday Cup Signal without suppression.

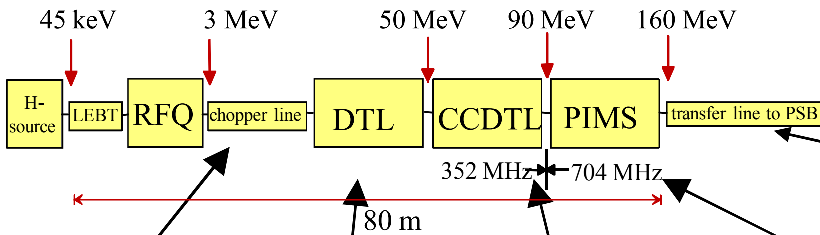
3. Purple= Current exiting source (1A/V).
4. Green=RF reflected power.

Linac4 Status – May 2009

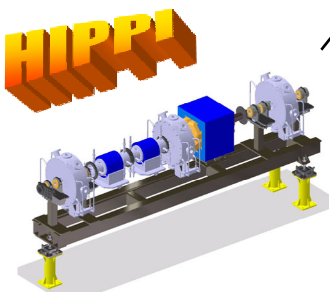


- 3 MeV Test stand for Linac4 Front-end (Bld. 152):
  - Infrastructure completed.
  - Prototype modulator and LEP klystron under test.
  - Ion source completed, first plasma mid-June.
  - Chopper line completed.
  - RFQ in construction at CERN Workshop.
- Prototypes of accelerating structures tested (CCDTL), under test (DTL), in construction (PIMS). Construction of DTL and CCDTL start in 2009, material being procured.
- Started preparation of large contracts (klystrons, modulators, magnets,…).
- Setting up network of international collaborations to contribute to Linac4 construction (France in-kind, Russia-EU, India, Poland, …) – see next slide.

Status of Linac4 collaborations



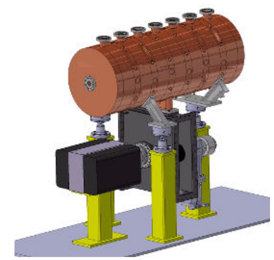
Transfer line vacuum chambers and supports from Pakistan, *AGREED*



Chopper line in a EU Joint Research Activity *COMPLETED*

Discussions with Saudi Arabia (DTL tanks) and ESS-Bilbao (drift tubes)

ISTC Project (Russia-EU) for CCDTL *APPROVED*



Collaboration agreement with Poland to build the PIMS structure, *in preparation.*

Tuners, couplers, waveguides from India, *in preparation*

French in-kind contribution: RFQ design & test, RF amplifiers, modulators - *being signed*

US contribution: Laser Profile monitor (+ extension), *under discussion*…

Linac4 Master Plan

New Masterplan for MTP – some modifications with respect to the plan presented on 12.03

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 prototyping
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 (3 + 10 MeV)
19	Cavities testing, conditioning
20	Cabling, waveguides installation
21	Accelerator installation
22	Klystrons, modulators installation
23	Hardware tests
24	Front-end commissioning
25	Linac accelerator commissioning
26	Transfer line commissioning
27	PSB modifications
28	PSB commissioning with Linac4
29	**PSB beam ready for PS**

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.

Linac4 WBS

LINAC4

- **1. Management,** *M. Vretenar + core team –* ***Deputies*** *A. Lombardi, S. Maury*
- **2. Linac Systems**
  - **2.1 Ion Source and LEBT,** *R. Scrivens, BE/ABP*
  - **2.2 Radio Frequency Quadrupole**
    - **2.2.1 RFQ Funct. design, Commissioning,** *C. Rossi, BE/RF*
    - **2.2.2 RFQ Mech. design, Fabrication,** *S. Mathot, EN/MME*
  - **2.3 Chopper Line,** *A. Lombardi, BE/ABP*
  - **2.4 Accelerating Structures,** *F. Gerigk, BE/RF*
    - **2.4.1 Drift Tube Linac,** *S. Ramberger, BE/RF*
    - **2.4.2 CCDTL and PIMS,** *F. Gerigk, BE/RF*
  - **2.5 Linac Beam Dynamics,** *A. Lombardi, BE/ABP*
  - **2.6 Radio Frequency Systems**
    - **2.6.1 Low Level RF Systems,** *P. Baudrenghien, BE/RF*
    - **2.6.2 High Power RF Systems,** *O. Brunner, BE/RF*
    - **2.6.3 Slow Tuning and Interlocks,** *L. Arnaudon, BE/RF*
    - **2.6.4 Buncher Amplifiers,** *J. Broere, BE/RF*
  - **2.7 Beam Instrumentation,** *U. Raich, BE/BI*
  - **2.8 Transfer Line,** *S. Maury BE/ABP*
  - **2.9 Magnets**
    - **2.9.1 Magnet Design and Procurement,** *T. Zickler, TE/MSC*
    - **2.9.2 Magnetic Measurements,** *M. Buzio, TE/MSC*
  - **2.10 Power Converters,** *D. Nisbet, TE/EPC*
  - **2.11 Vacuum Systems,** *G. Vandoni, TE/VSC*
  - **2.12 Control Systems,** *I. Kozsar, BE/CO*
  - **2.13 Beam Intercepting devices,** *Y. Kadi, EN/STI*
  - **2.14 Machine Interlocks,** *B. Puccio, TE/MPE*
- **3. Booster Systems**
  - **3.1 PS Booster Injection,** *W. Weterings,TE/ABT*
  - **3.2 PSB Beam Dynamics,** *C. Carli, BE/ABP*
- **4. Installation commiss.**
  - **4.1 Test Stand Operation,** *C. Rossi, BE/RF*
  - **4.2 Transport and Installation,** *C. Bertone, EN/HE*
  - **4.3 Survey,** *M. Jones, BE/ABP*
  - **4.4 Linac Commissioning,** *A. Lombardi, BE/ABP*
  - **4.5.1 PSB Commissioning to nominal,** *K. Hanke, BE/OP*
  - **4.5.2 PSB Commissioning to ultimate,** *C. Carli, BE/ABP*
- **5. Building, Infrastruct.**
  - **5.1 Building Design, Construction,** *L.A. Lopez, GS/SEM*
  - **5.2 Cooling and Ventilation,** *Y. Body, EN/CV*
  - **5.3 Electrical Systems,** *J. Pierlot, EN/EL*
  - **5.4 Access Systems,** *D. Chapuis, GS/ASE*

- **Integration, Safety Coordination,** *S. Maury, BE/ABP*
- **Technical Coordination,** *R. Maccaferri, TE/MSC*
- **Specification Committee** *T. Kurtyka, DG/PRJ*
- **Collaborations – India,** *V. Chohan, EN/MEF*
- **Collaborations – Russia, Poland** *T. Kurtyka, DG/PRJ*

LINAC4 WBS
06-2009

DRAFT