Linac4

a new linear accelerator for the CERN complex

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1. Status and planning
2. Linac4 design
3. The new building

The Linac4 project

☞ At its June 2007 Meeting, the CERN Council has approved the "White Paper", first presented to the Council in October 2006.

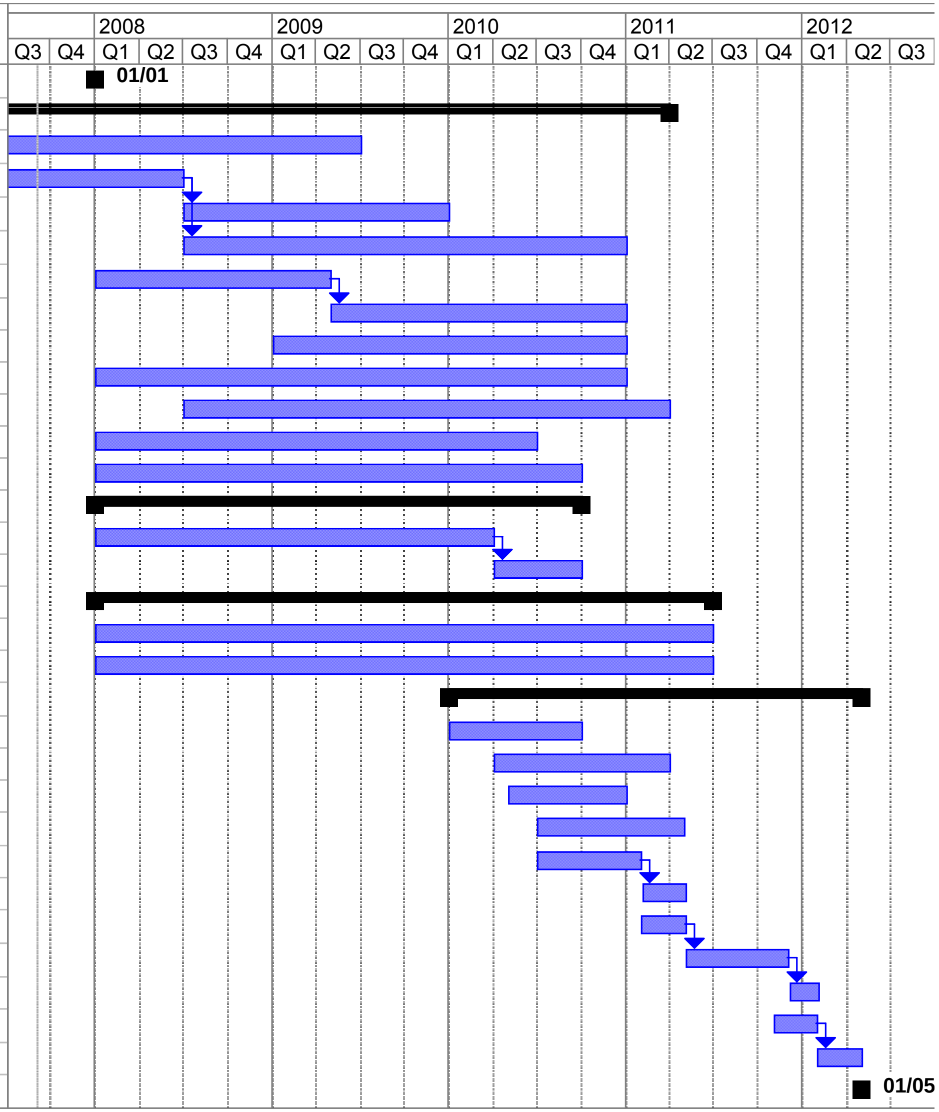
☞ The approved programme includes (2nd Theme, high priority programme to be achieved by 2011, in order to eliminate concerns about reliability and remove technical bottlenecks in the present injection line):

- ❑ construction of Linac4 (160 MeV, H-), which will replace Linac2 as injector to the PS Booster (55 MCHF+115 MY).
- ❑ design of a Superconducting Proton Linac (SPL) replacing PSB (40 MY).
- ❑ design of a new PS (PS2) (30 MY).

☞ Construction of Linac4 is approved as a high priority project intended to start in January 2008 and last 4 years (2008-11). The 2012 PSB start-up is foreseen with the new Linac4 beam.

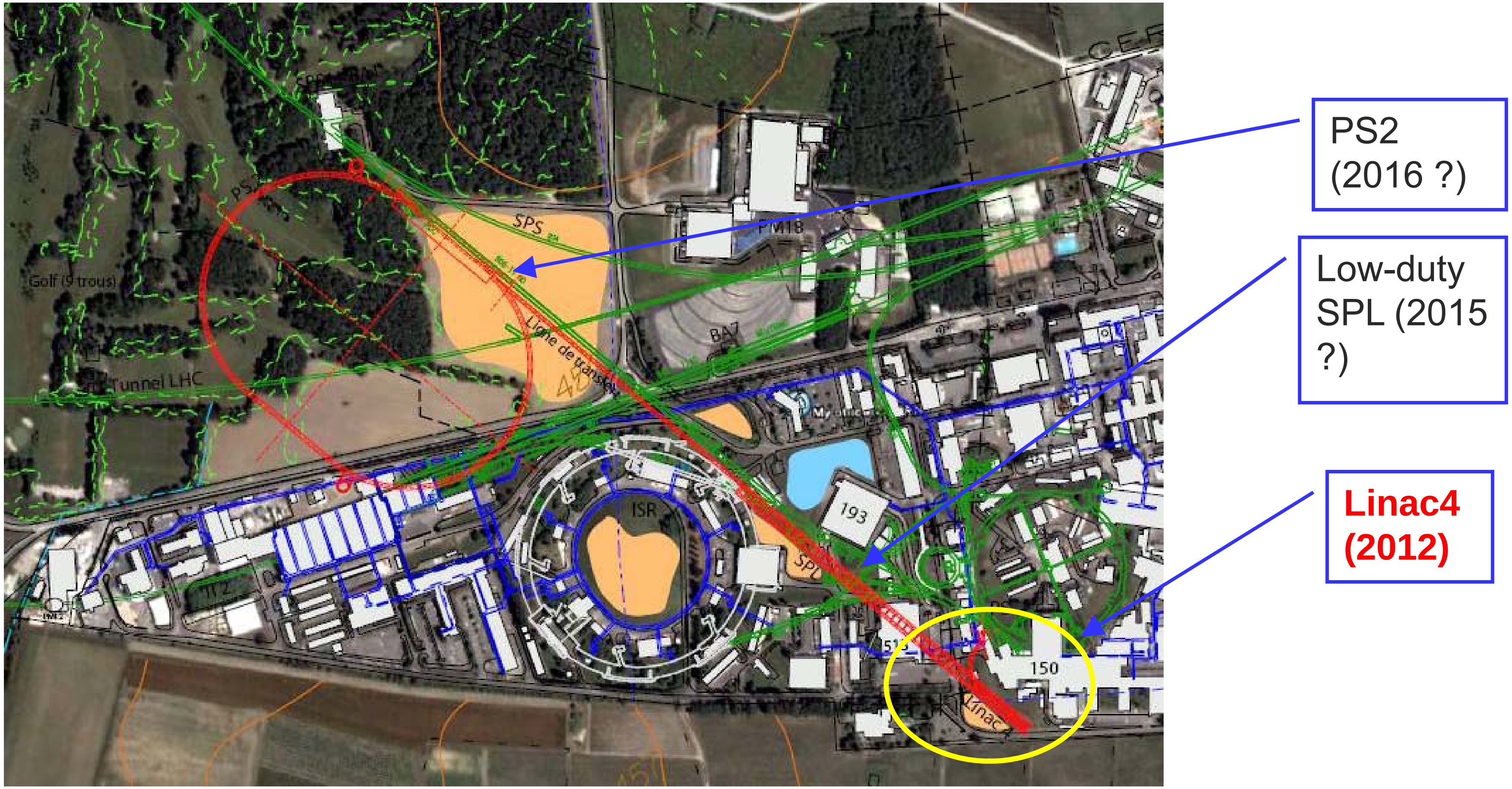
Linac4 Master Plan

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 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 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**



Planning based on the White paper requirements (end of project 2011), still to be confirmed for the building construction, which is on the critical path.

Linac4 and the new injectors



1st stage: Linac4 injects into the old PSB → increased brightness for LHC, more beam to ISOLDE, increased reliability.

2nd stage: Linac4 into SPL (and PS2) → renewed and improved LHC injection chain.

Some concerns

☞ The original Linac4 budget in the White Paper was based on construction in an existing building (PS South Hall) and on a preliminary cost estimate prepared in March 2006.

☞ Since, the concept of the new integrated layout of the LHC injectors has been introduced, and a new location under the Mont Citron defined. However, the cost of this new building is not included in the original White Paper estimate, and the time for the construction of this new building could have a significant impact on the schedule.

The 3 lives of Linac4

Linac4 is foreseen to operate in 3 different modes:

1. Injector to PSB *(2012-2016?):* 160 MeV, 2 Hz, 40 mA, 400 μs.
2. Injector to LP-SPL *(2016-2020?):* 180 MeV, 1 Hz, 20 mA, 1.2 ms
3. Injector to HP-SPL *(if approved, >2020):* 180 MeV, 50 Hz, 40 mA, 400 μs

- ☞ Upgrade in energy and connection to LP-SPL around 2016
- ☞ Upgrade in beam power after 2020

Consequences on the design:

1. Shielding dimensioned for the high beam power operation
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

Linac4 parameters

Ion species	H−	
Output Energy	160	MeV
Bunch Frequency	352.2	MHz
Max. Rep. Rate	2	Hz
Beam Pulse Length	400	µs
Max. Beam Duty Cycle	0.08	%
Chopper Beam-on Factor	62	%
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 $\beta\gamma^2$) → more accumulated particles in the PSB.

Will re-use 352 MHz LEP RF components: klystrons, waveguides, circulators.

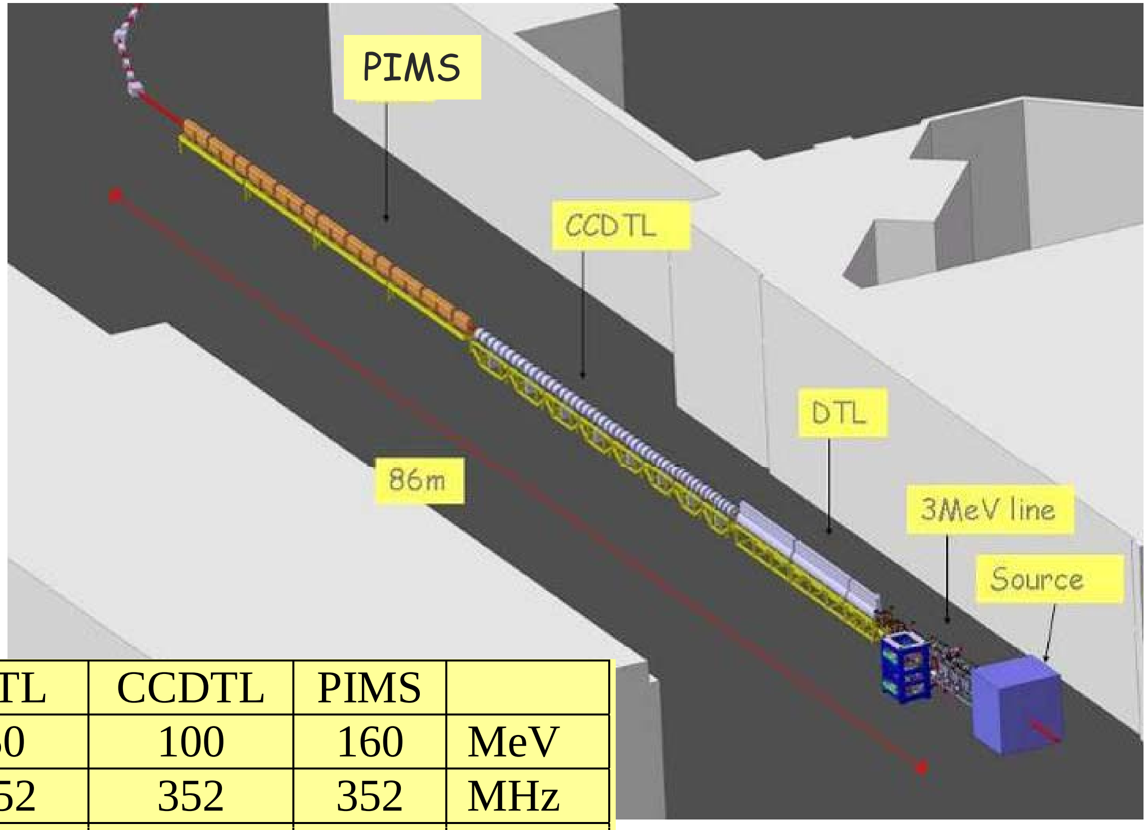
2 operating modes: low duty for LHC, high duty for high-power SPL (neutrino or RIB physics) at a later stage.

- Structures and klystrons dimensioned for 50 Hz
- Power supplies and electronics dimensioned for 2 Hz.

The Linac4 accelerating structures

Linac4 accelerates H- ions up to 160 MeV energy:

- in about 86 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	100	160	MeV
Frequency	352	352	352	352	MHz
No. of resonators	1	3	7	12	
Gradient E_0	-	3.2	3.9-3.1	3.9	MV/m
Max. field	1.7	1.6	1.7	1.8	Kilp.
RF power	1	4.7	7	11.3	MW
No. of klystrons	1	1+2	7	4+4	
Length	6	18.7	25	22	m

An 70 m long transfer line connects to the existing line to the PS Booster

Linac4 Layout

95keV → 3MeV → 3MeV → 50MeV → 94MeV → 160MeV

H-	RFQ	CHOPPER	DTL	CCDTL	PIMS
RF volume source (DESY) 35 kV Extrac. +60kV Postacc.	Radio Frequency Quadrupole (IPHI) 352 MHz 6 m 1 Klystron 1 MW	Chopper 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

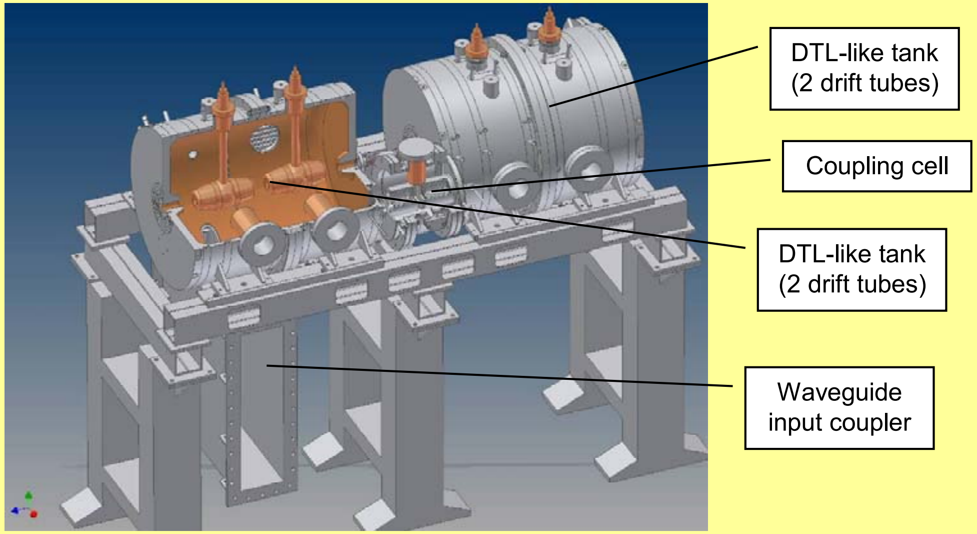
Total Linac4:
80 m,
18 klystrons

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

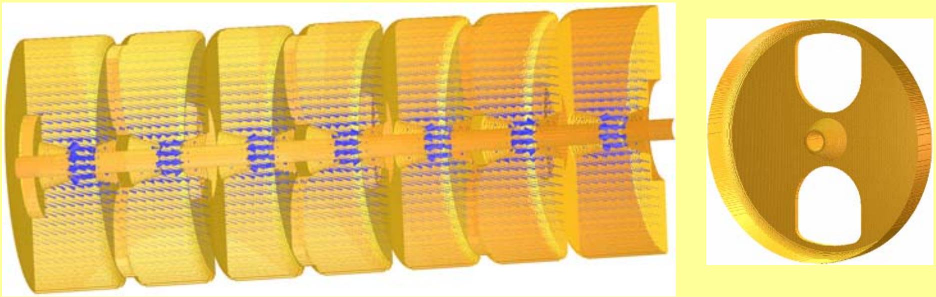
4 different structures,
(RFQ, DTL, CCDTL, PIMS)

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

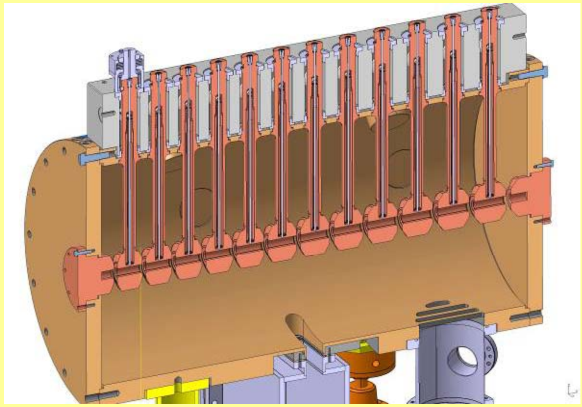
The Linac4 accelerating structures



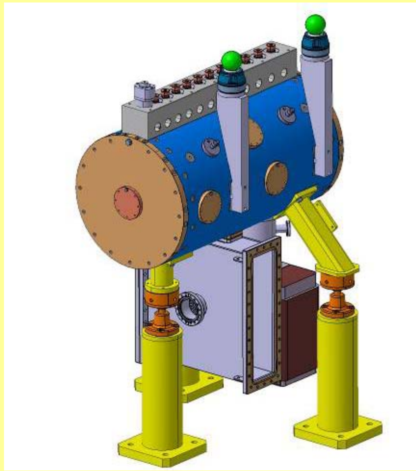
CCDTL: 2 prototypes built and tested



PIMS (7-cell pi-mode cavities): advanced design, prototype being designed



DTL: prototype in construction



Main changes to Linac4 design in 2007

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.

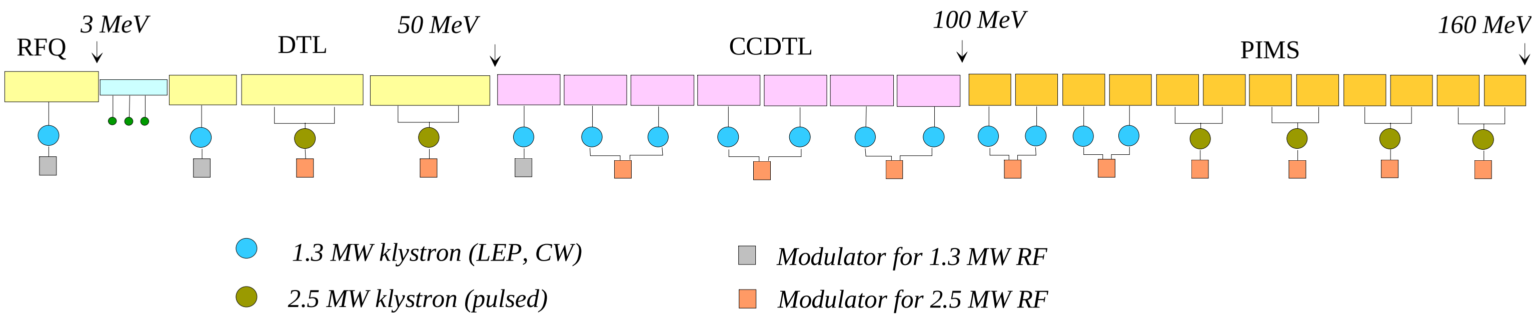
+ improvements to all accelerating structures.

☞ The general design is now frozen.

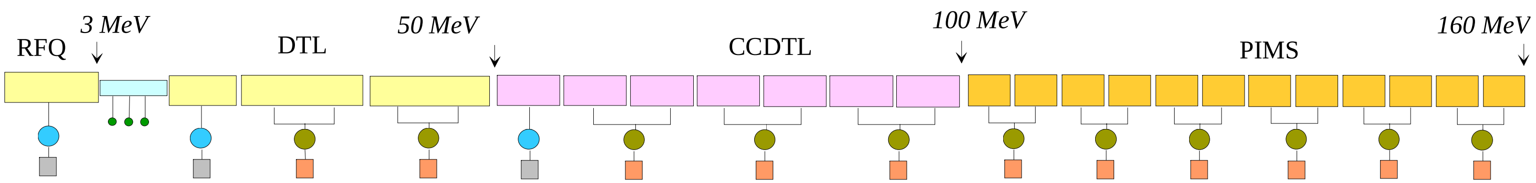
The Linac4 Radio Frequency system

Linac4 will reuse the stock of high-power klystrons coming from the old LEP accelerator:

Initial configuration:
13 klystrons 1.3 MW, 6 klystrons 2.5 MW, 3 modulators 1.3 MW, 11 modulators 2.5 MW

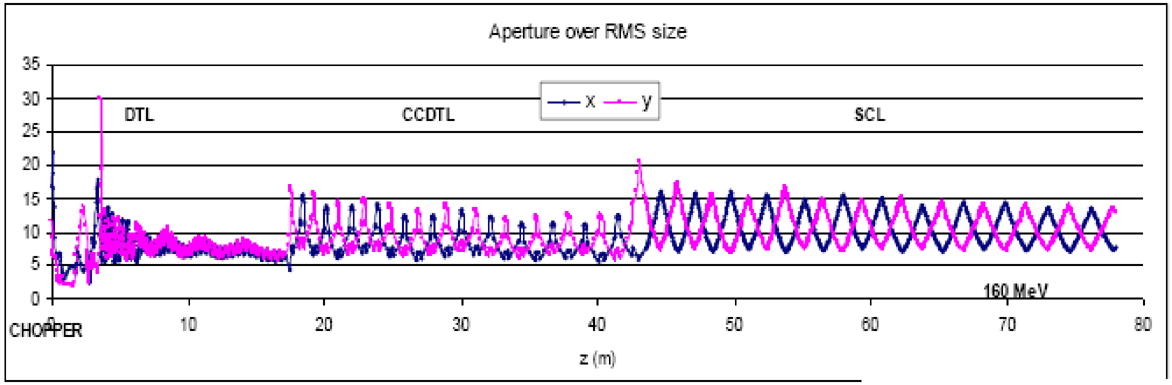


Final configuration (at the end of the stock of LEP klystrons):
3 klystrons 1.3 MW, 11 klystrons 2.5 MW, 3 modulators 1.3 MW, 11 modulators 2.5 MW

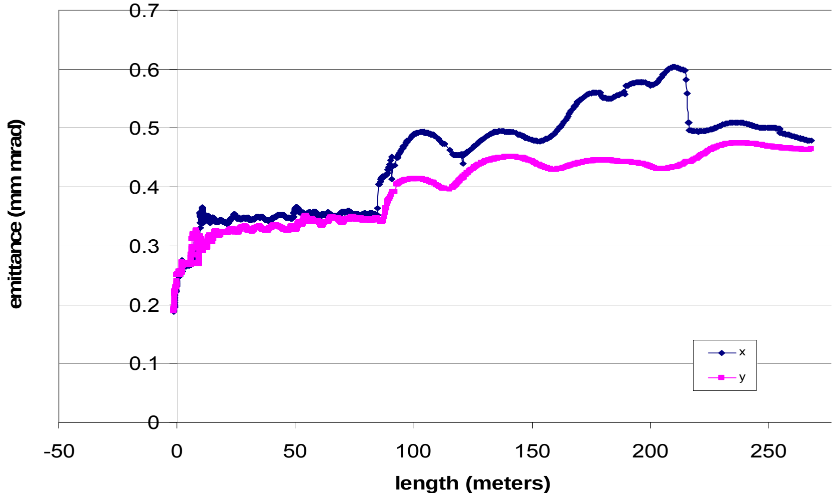


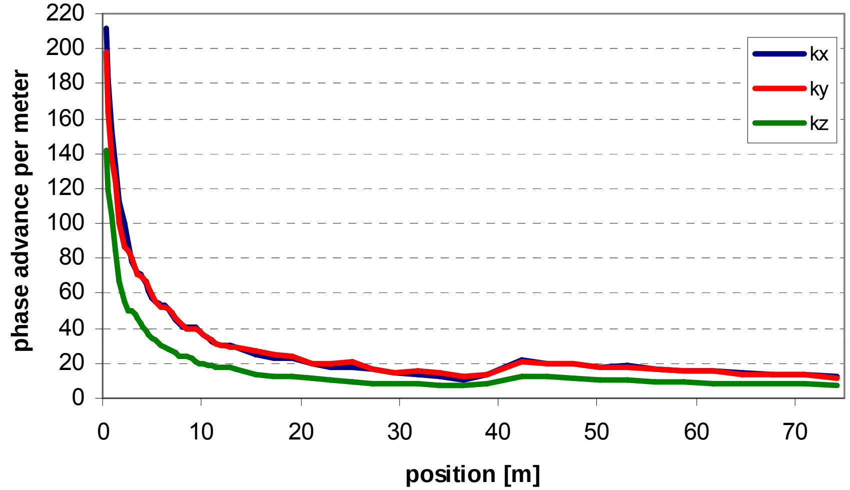
Linac4 Beam Dynamics

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.



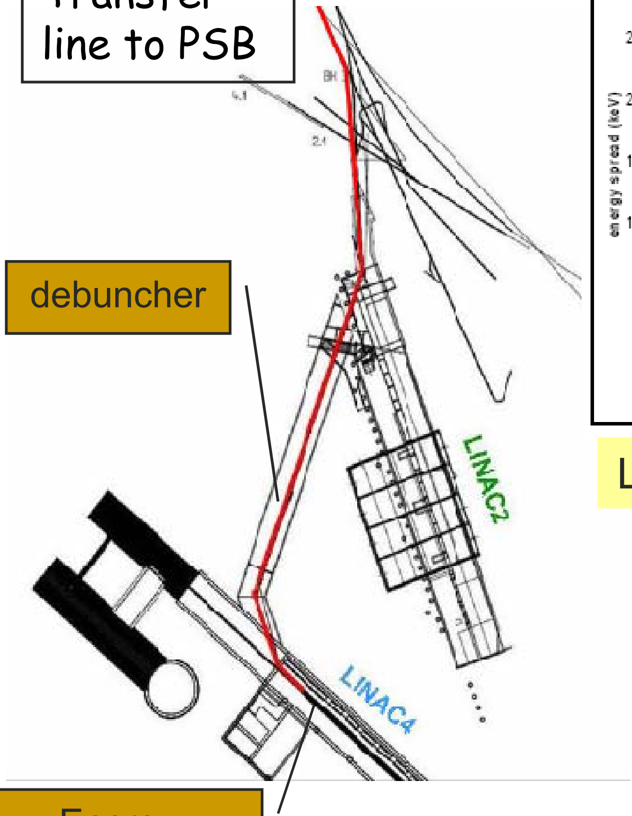


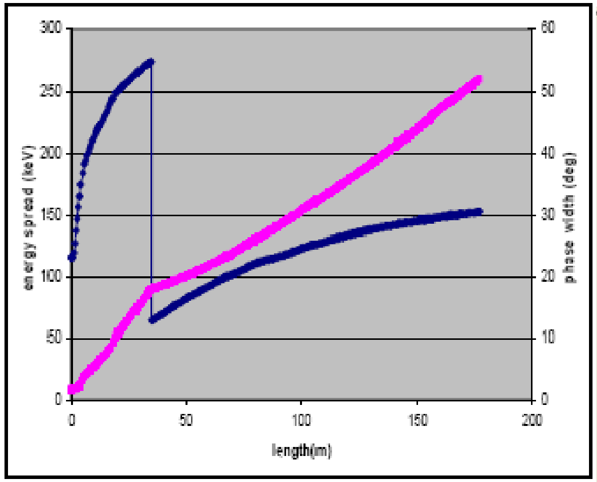
Linac4 Beam – Longitudinal Painting

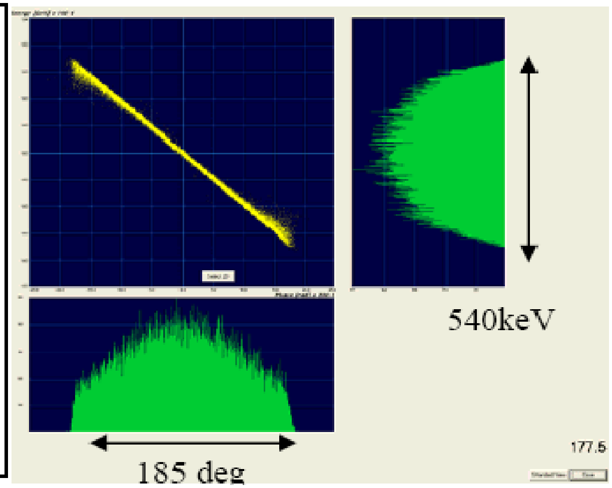
Transfer line to PSB

debuncher

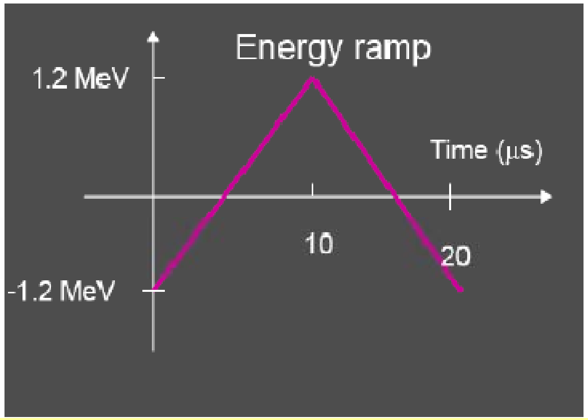
Energy modulation with last 2 PIMS cavities

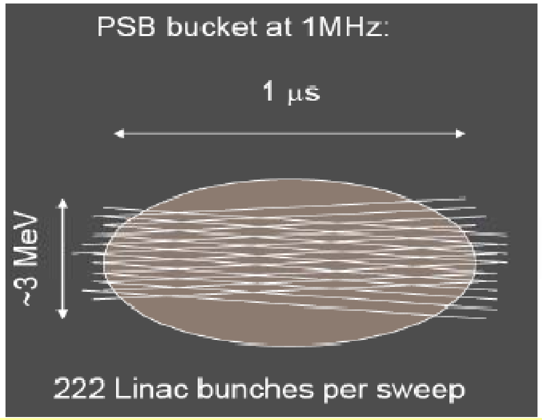






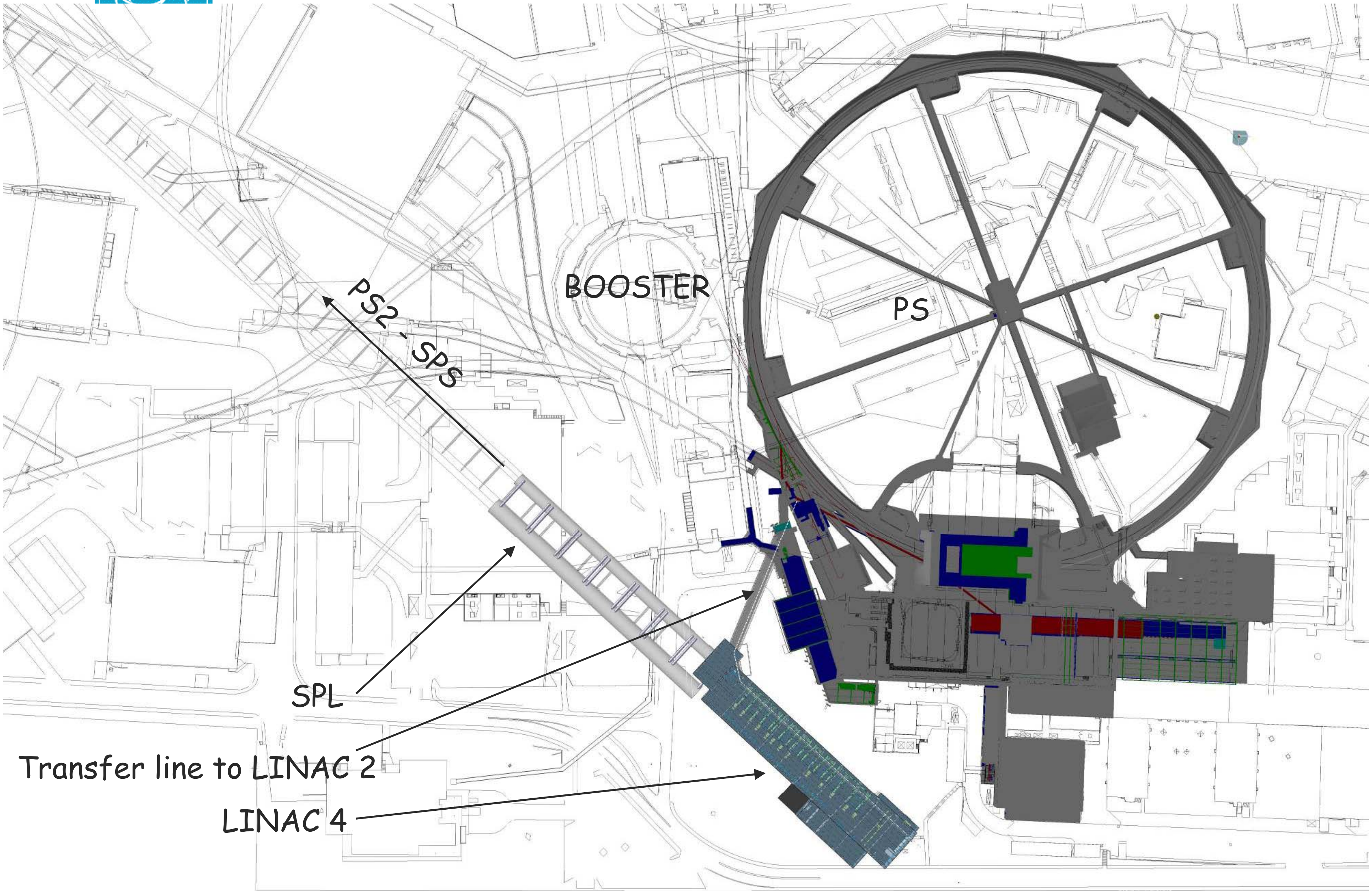
Longitudinal beam parameters along line and at PSB entrance

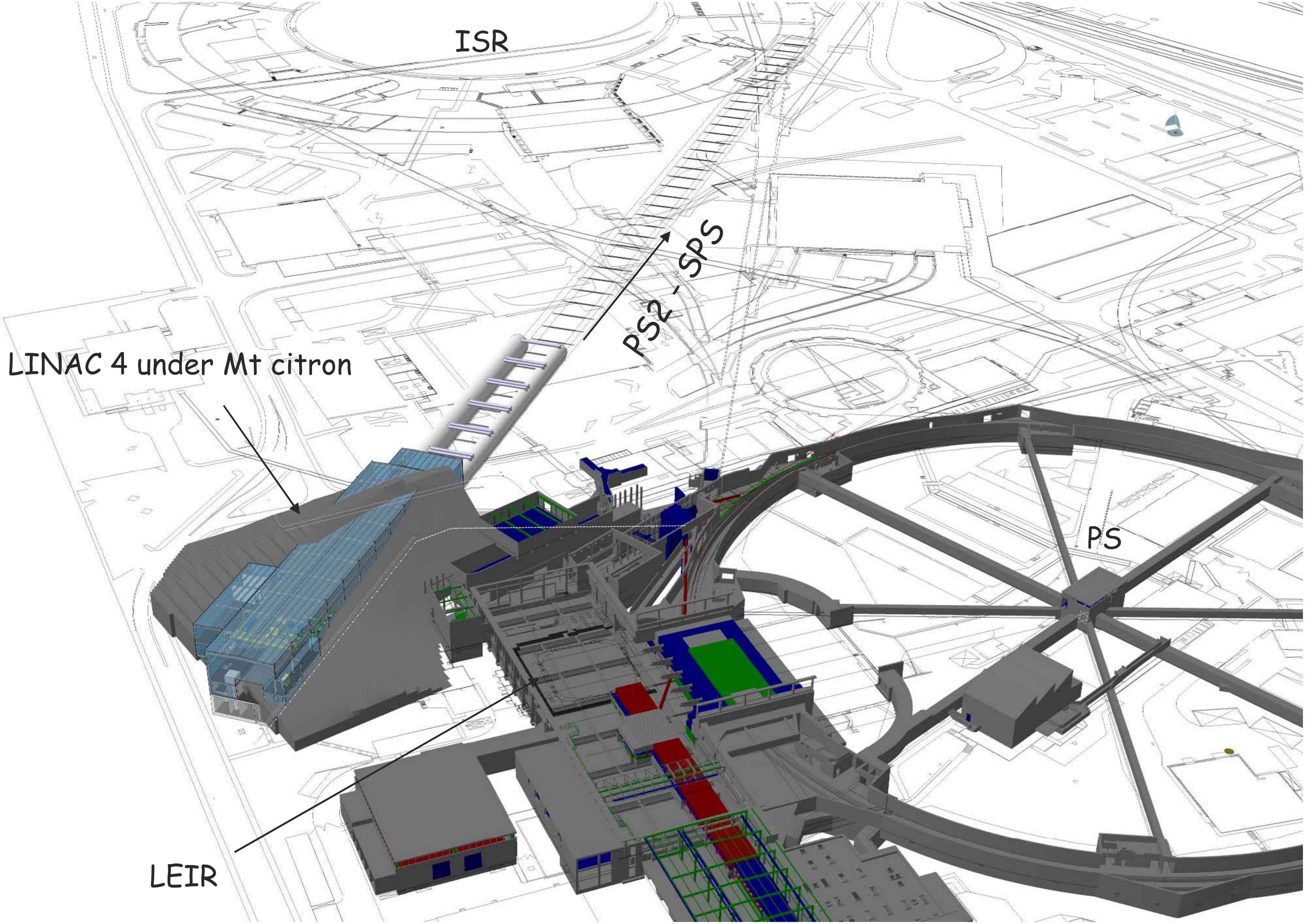


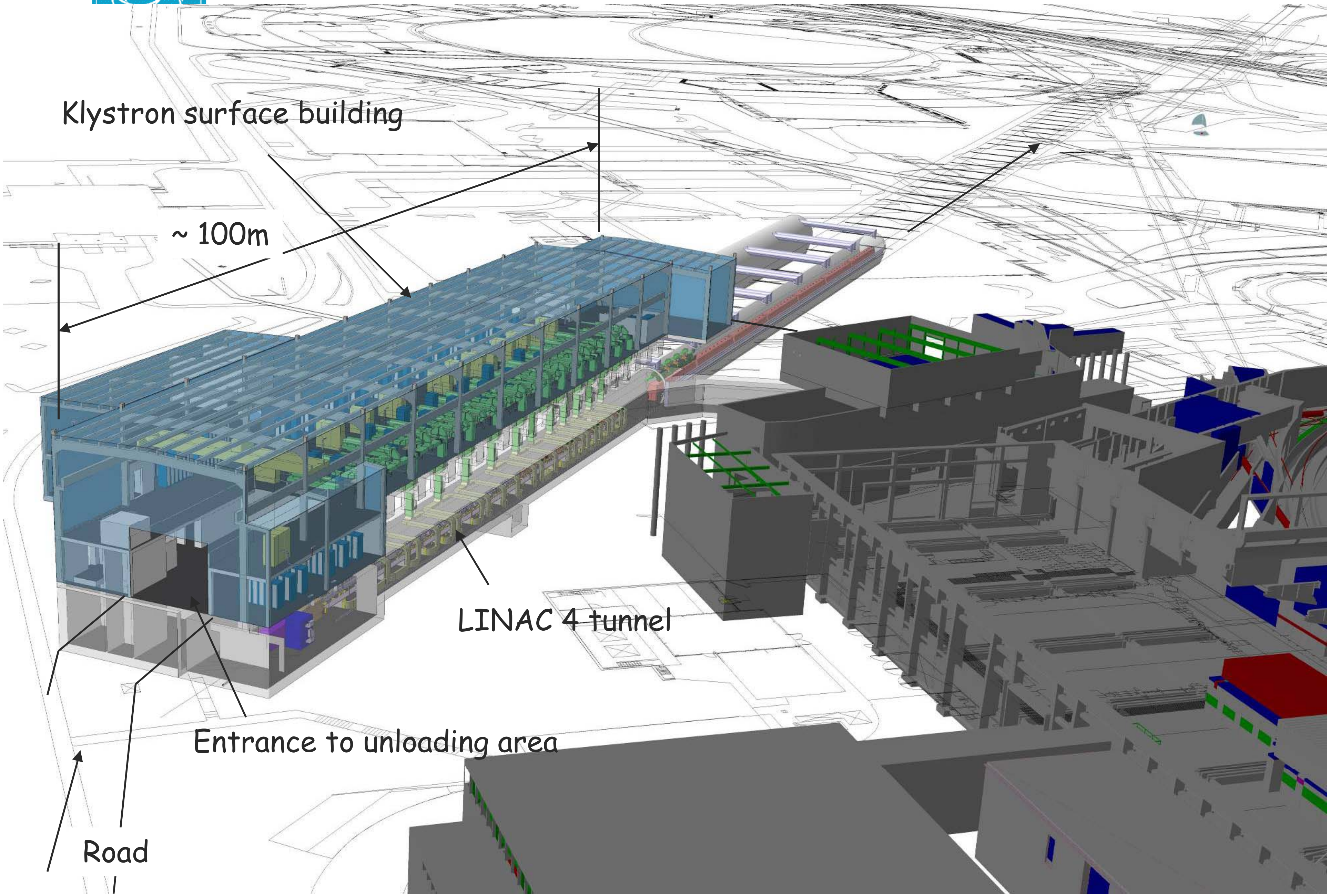


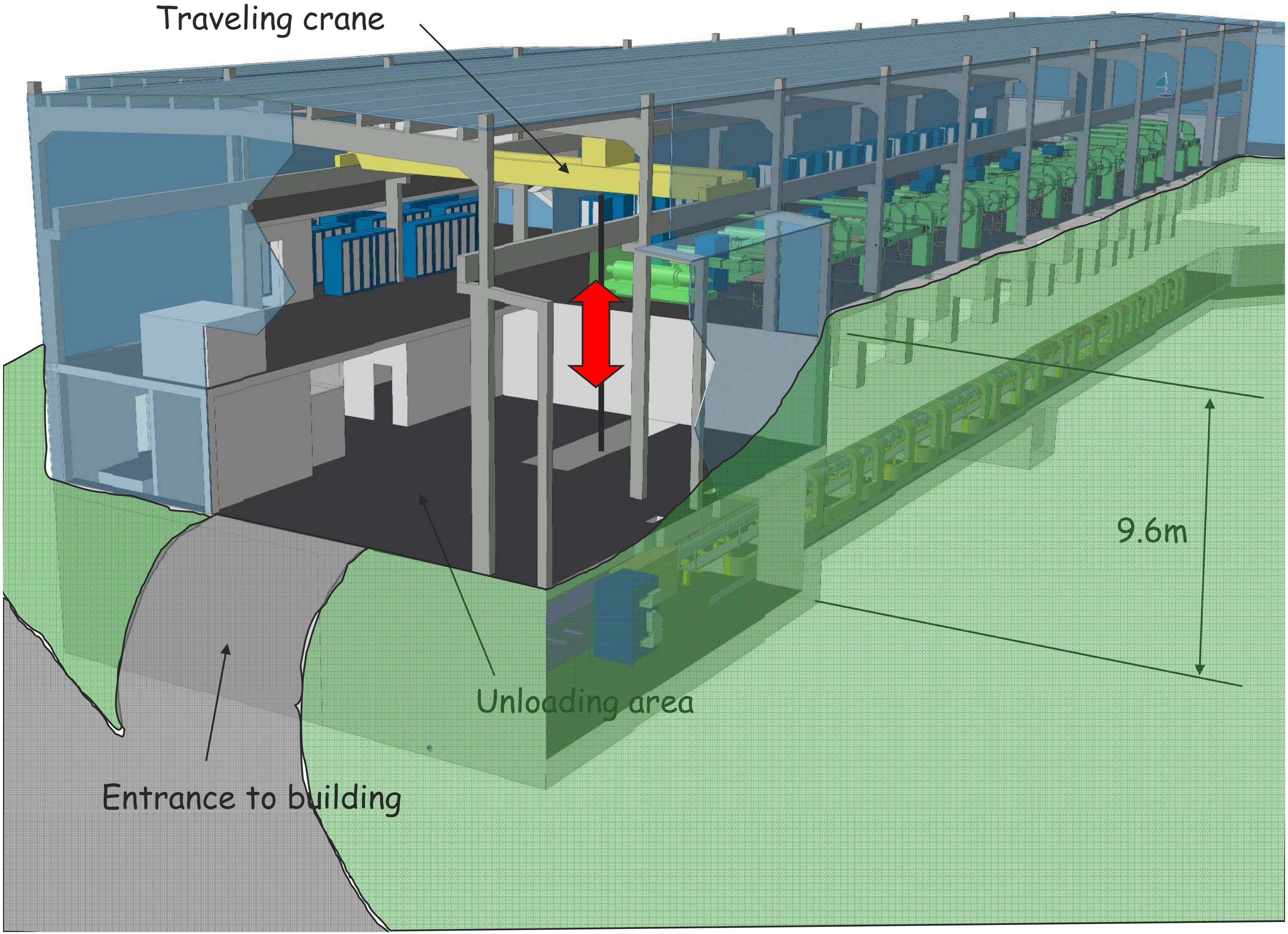
Painting scheme: linear energy ramp over 10+10 PSB buckets (with low energy chopping limiting sweep to 222 linac bunches)

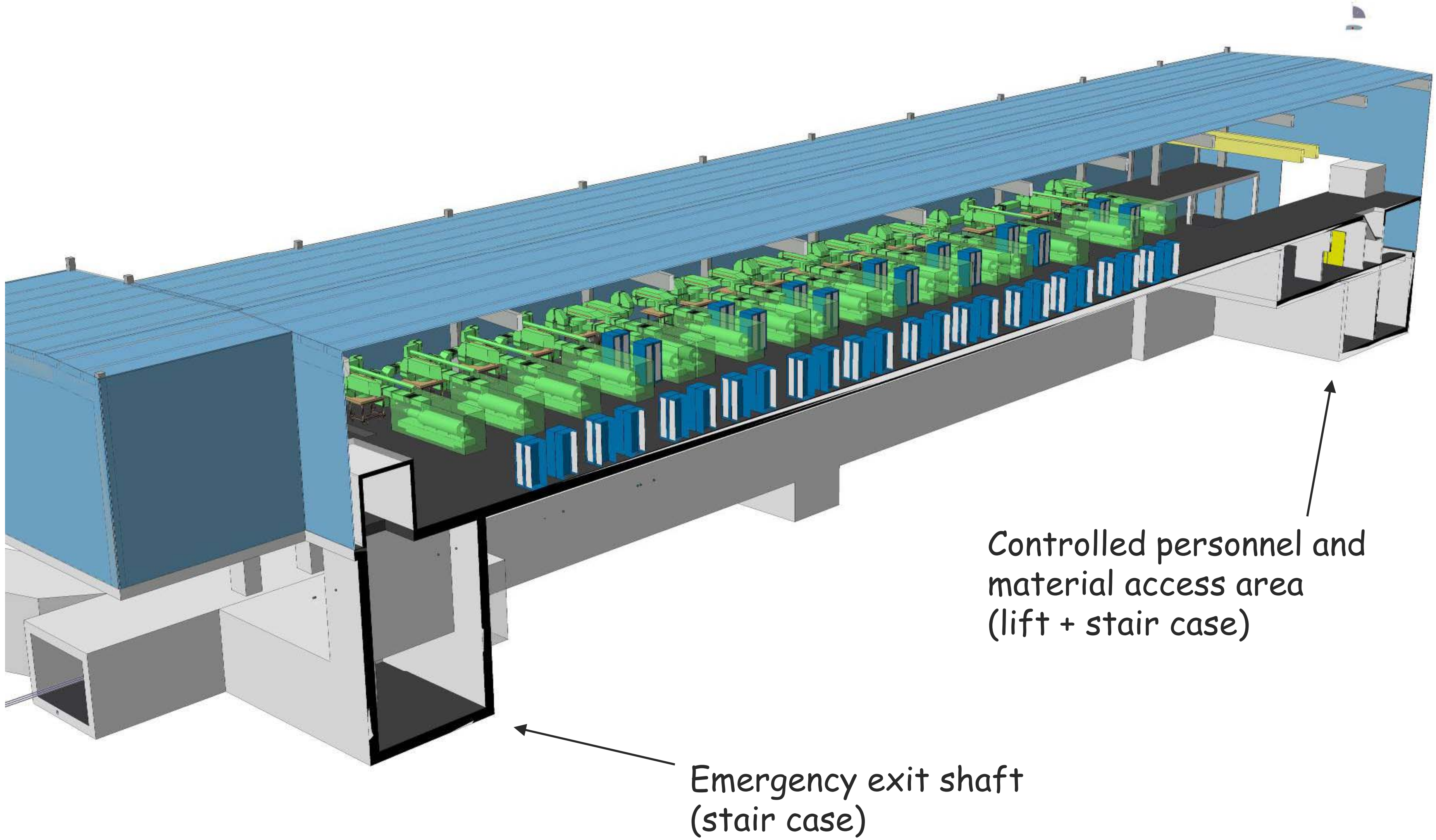
Linac4 in the new building

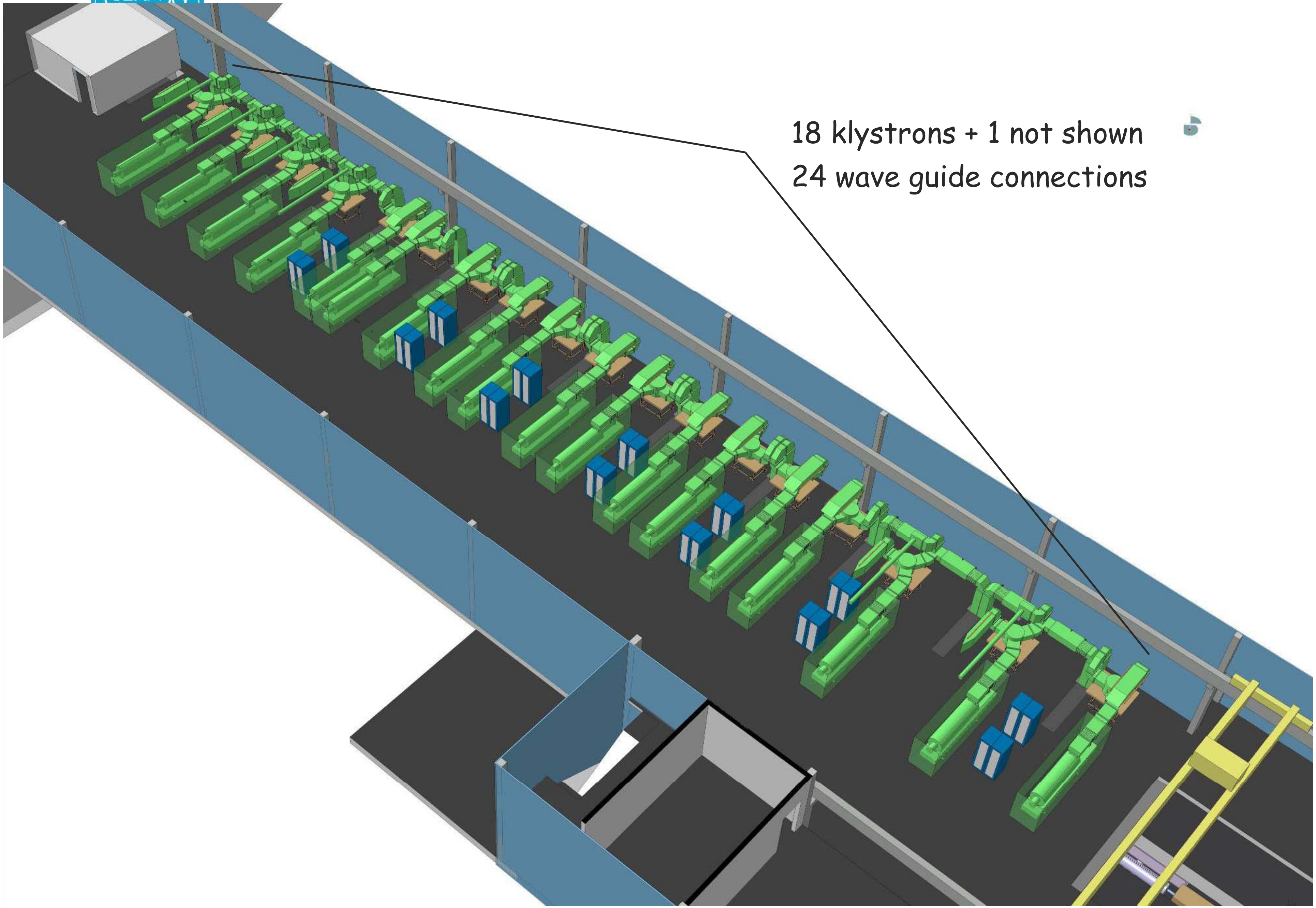

BOOSTER
PS
PS2 - SPS
SPL
Transfer line to LINAC 2
LINAC 4


ISR
PS2 - SPS
LINAC 4 under Mt citron
PS
LEIR

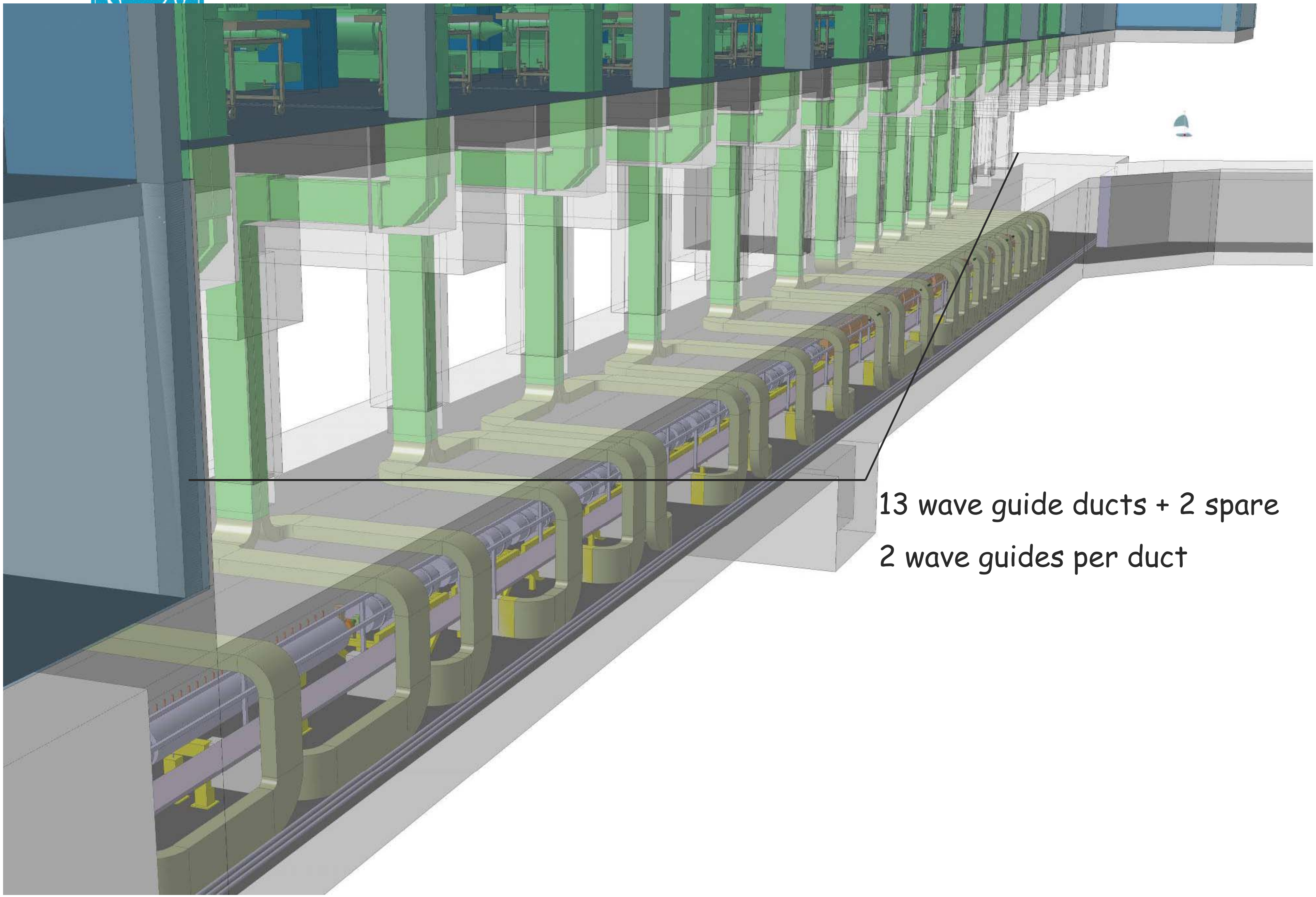

Klystron surface building
~ 100m
LINAC 4 tunnel
Entrance to unloading area
Road

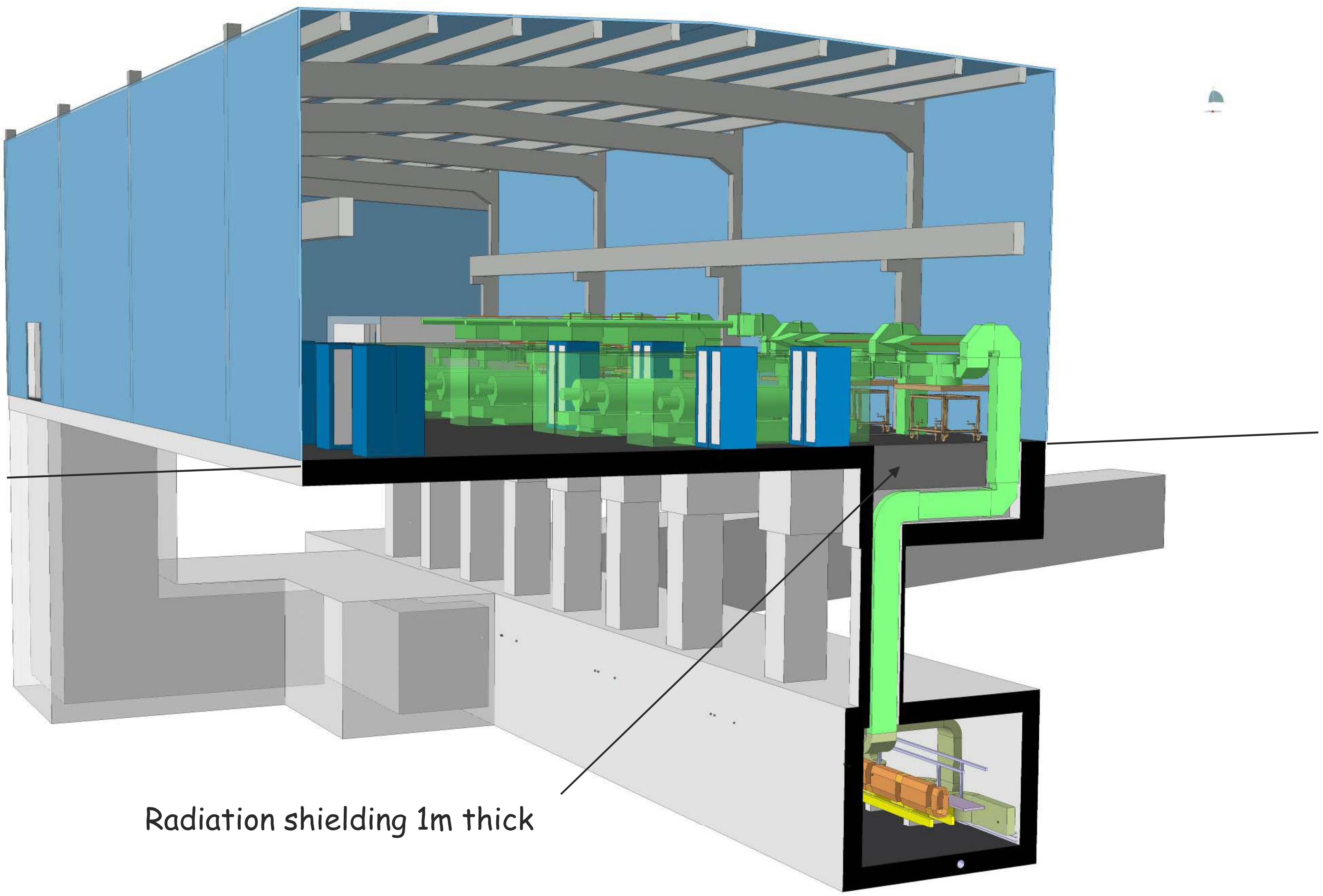

Traveling crane
9.6m
Unloading area
Entrance to building

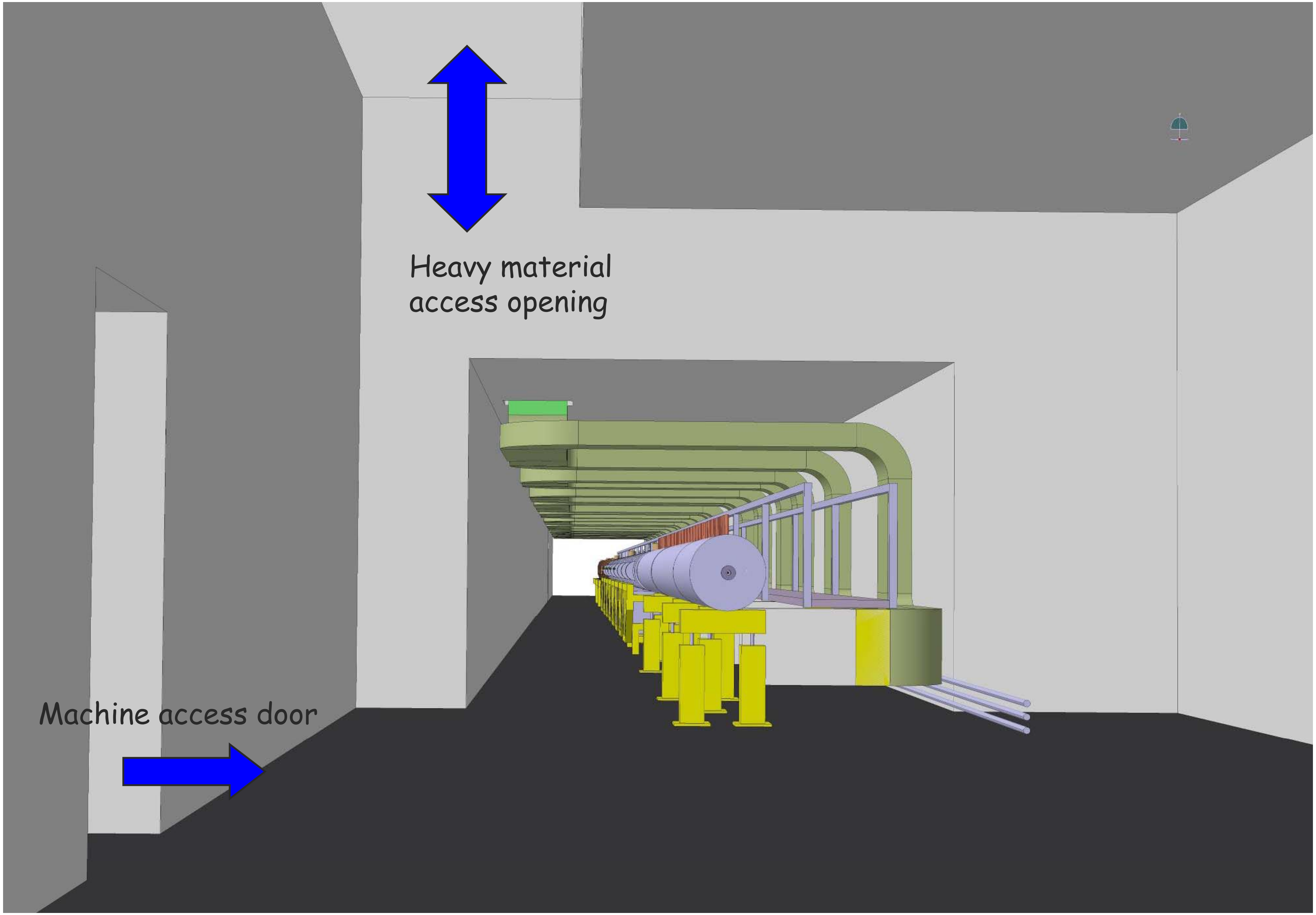

Controlled personnel and
material access area
(lift + stair case)
Emergency exit shaft
(stair case)

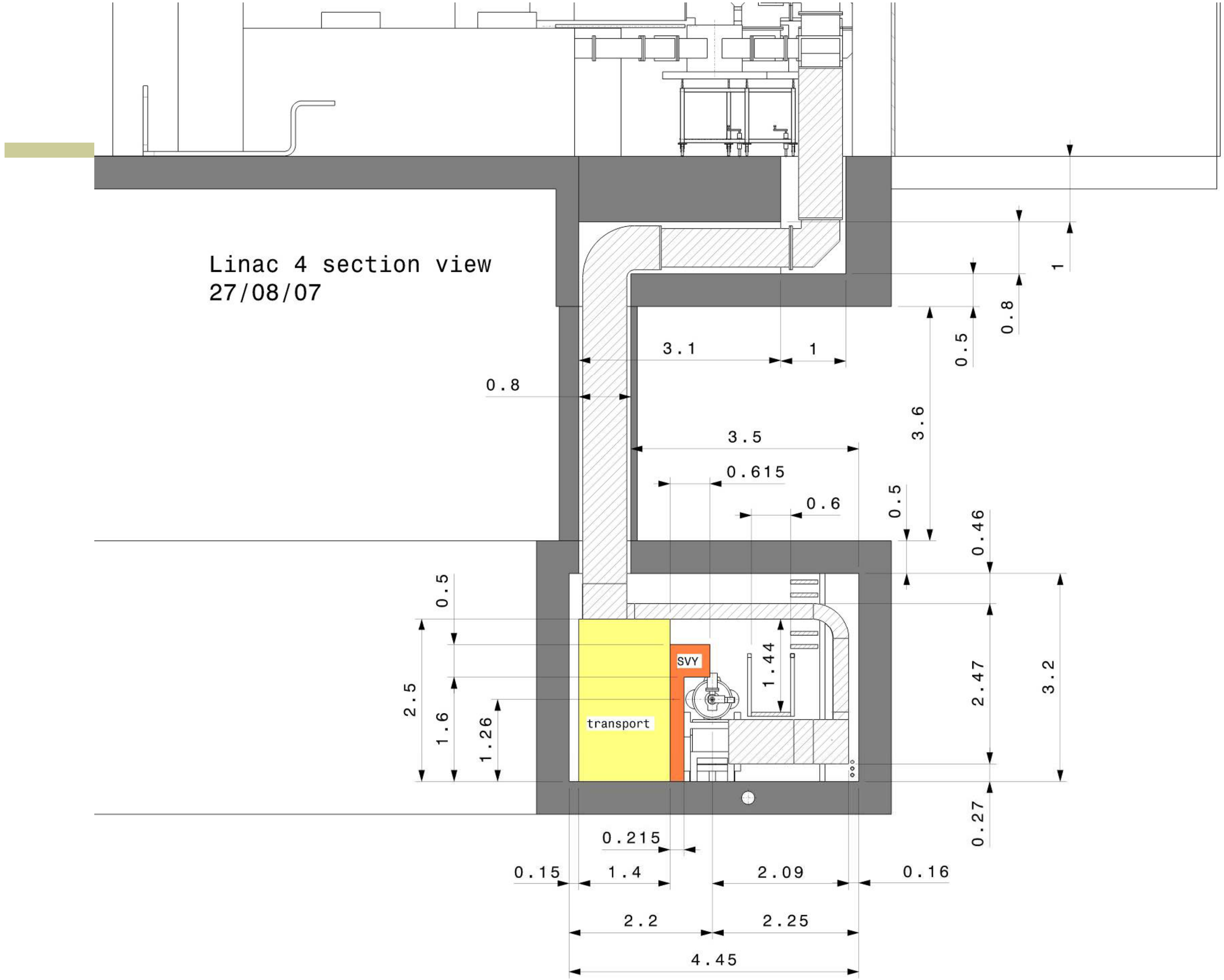


18 klystrons + 1 not shown
24 wave guide connections


13 wave guide ducts + 2 spare
2 wave guides per duct


Radiation shielding 1m thick


Heavy material
access opening
Machine access door


Linac 4 section view
27/08/07
3.1
1
0.8
3.5
0.615
0.6
0.5
3.6
0.5
0.8
1
0.46
0.5
2.5
1.6
1.26
1.44
SVY
transport
2.47
3.2
0.27
0.215
0.15
1.4
2.09
0.16
2.2
2.25
4.45