Linac4 Advisory Committee – 29 January 2008

Plans for new LHC injectors

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Content

- Introduction: new activities 2008-2011
- Scenarios for the upgrade of the accelerators
- Linac4 / SPL / PS2
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New Activities 2008-2011 (1/2)

Quote from R. Aymar (16 January 2008)

The Strategy for European Particle Physics, adopted by CERN Council in July 2006, ranks its most important component in the exploration of the new territory opened up by the Large Hadron Collider (LHC). **To fully exploit this rich physics potential, CERN's resources will be concentrated on the operation of the LHC and the experiments being constructed for it**. The LHC will determine the future course of high energy physics: this notion is central in the European Strategy and defines the priorities in the scientific and R&D programme.

The funding of the new activities requires additional resources amounting in total to 240 MCHF for the period 2008-2011, during which the large bank loans that had to be taken out to build the LHC will be reimbursed.

The additional resources are vital for preserving the Laboratory's capacity for scientific and technical innovation. Their non-availability would have irreversible and ultimately dramatic consequences.

The new activities were presented to Council and its committees in the White Paper of October 2006, and were subsequently reviewed by a panel established for the purpose by the Scientific Policy Committee. The results of the review have been taken into account in preparing the final proposal in June 2007, which has been agreed by Council while half of the financial burden is born by the two Host States.

New Activities 2008-2011 (2/2)

Quote from R. Aymar (16 January 2008)

- Follows the directions of the « European Strategy for Particle Physics » approved by the Council at Lisbon in July 2006
- Plan structured in 3 + 1 themes
- First theme: *« to fully exploit the physics potential of LHC »*
  - Final implementation of the four experiments
  - Enhanced capacity for physics data analysis
  - Consolidation/improvements to enhance luminosity in the short term
  - New inner triplets: upgrade of the LHC insertions « Phase I »
- Second theme: *« renovate the injector complex to improve reliability »*
  - Design of PS2 and SPL
  - Build LINAC4 as new front-end injector
- Third theme: *« accelerator and detector R&D for LHC luminosity upgrade, high-intensity ν facility and CLIC technology qualification »*
  - Superconducting magnet R&D: high-field and fast-cycled
  - LHC IR cryogenic upgrade study
  - Improved RF capture systems in SPS and LHC
  - Detector development for LHC and CLIC
  - Enhanced CLIC qualification programme with CTF3

UPGRADE SCENARIOS FOR THE ACCELERATORS

Today's performance for LHC

	Maximum energy	Required intensity/bunch (at high energy)	Obtained intensity/bunch (at ejection)	Limitations*
Linac2	**50 MeV**			◆ **Too low energy**
PSB	**1.4 GeV**		**~ ultimate beam**	◆ **Too low injection energy (space charge)**
PS	**25 GeV**		**$1.5\ 10^{11}$ p/b (~ 90 % of ultimate beam)**	◆ **Transition / Impedance ?** ◆ **Poor longitudinal match with SPS** ◆ **Reliability (age)**
SPS	**450 GeV**		**$1.15\ 10^{11}$ p/b (nominal beam)**	◆ **Too low injection energy** ◆ **e-cloud** ◆ **Impedance**
LHC **Nominal** **Ultimate**		**1.15×10^{11} p/b** **1.70×10^{11} p/b**	**???**	◆ **Too low injection energy (DA, Snap-back) ?** ◆ **e-cloud ?**

Unexpected beam loss: > 10 %

Conclusion – OK for the first phase of operation of LHC, but:

- **bottleneck for reaching "ultimate" characteristics**
- **major risk of poor reliability due to age and performance stretch**

Needs of SLHC

(from F. Zimmermann)

parameter	symbol	25 ns, small β^*	50 ns, long
transverse emittance	ε [μm]	3.75	3.75
protons per bunch	N_b [10^{11}]	1.7	4.9
bunch spacing	Δt [ns]	25	50
beam current	I [A]	0.86	1.22
longitudinal profile		Gauss	Flat
rms bunch length	σ_z [cm]	7.55	11.8
beta* at IP1&5	β^* [m]	0.08	0.25
full crossing angle	θ_c [μrad]	0	381
Piwinski parameter	$\phi=\theta_c\sigma_z/(2^*\sigma_x^*)$	0	2.0
hourglass reduction		0.86	0.99
peak luminosity	L [10^{34} cm^{-2}s^{-1}]	15.5	10.7
peak events per crossing		294	403
initial lumi lifetime	τ_L [h]	2.2	4.5
effective luminosity ($T_{turnaround}$=10 h)	L_{eff} [10^{34} cm^{-2}s^{-1}]	2.4	2.5
	$T_{run,opt}$ [h]	6.6	9.5
effective luminosity ($T_{turnaround}$=5 h)	L_{eff} [10^{34} cm^{-2}s^{-1}]	3.6	3.5
	$T_{run,opt}$ [h]	4.6	6.7
e-c heat SEY=1.4(1.3)	P [W/m]	1.04 (0.59)	0.36 (0.1)
SR heat load 4.6-20 K	P_{SR} [W/m]	0.25	0.36
image current heat	P_{IC} [W/m]	0.33	0.78
gas-s. 100 h (10 h) τ_b	P_{gas} [W/m]	0.06 (0.56)	0.09 (0.9)
extent luminous region	σ_l [cm]	3.7	5.3
comment		D0 + crab (+ Q0)	wire comp.

Two new upgrade scenarios (LUMI'06)

Compromises between heat load and # pile up events

Upgrade procedure

1. Lack of reliability:

Ageing accelerators (PS is 48 years old !) operating far beyond initial parameters

⇒ 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

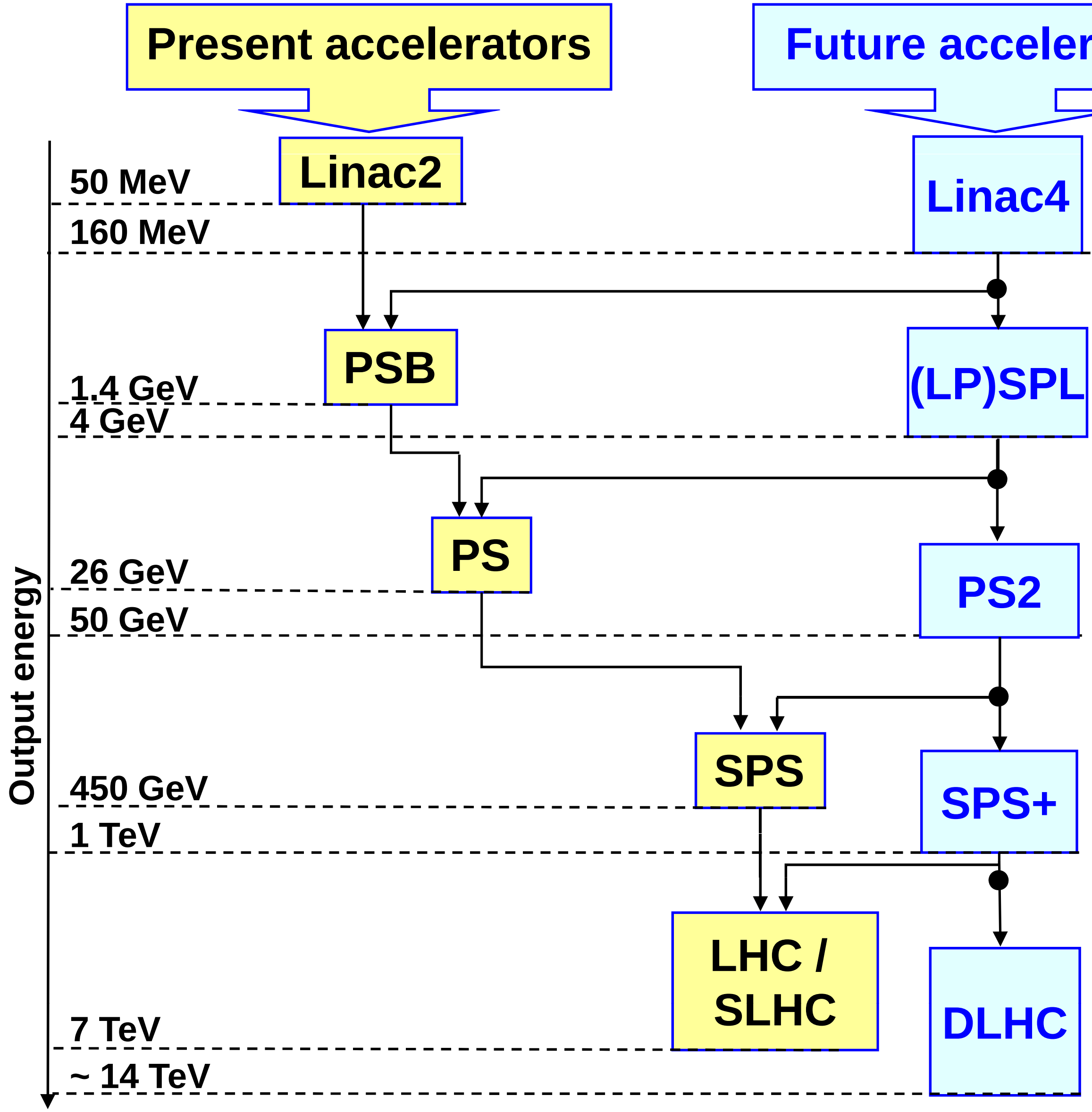
R : mean radius of the accelerator

$\beta\gamma$: classical relativistic parameters

⇒ 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**

Updated list of future accelerators



- (LP)SPL is the baseline injector for PS2
- PS2 size is 15/77 of SPS

(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)

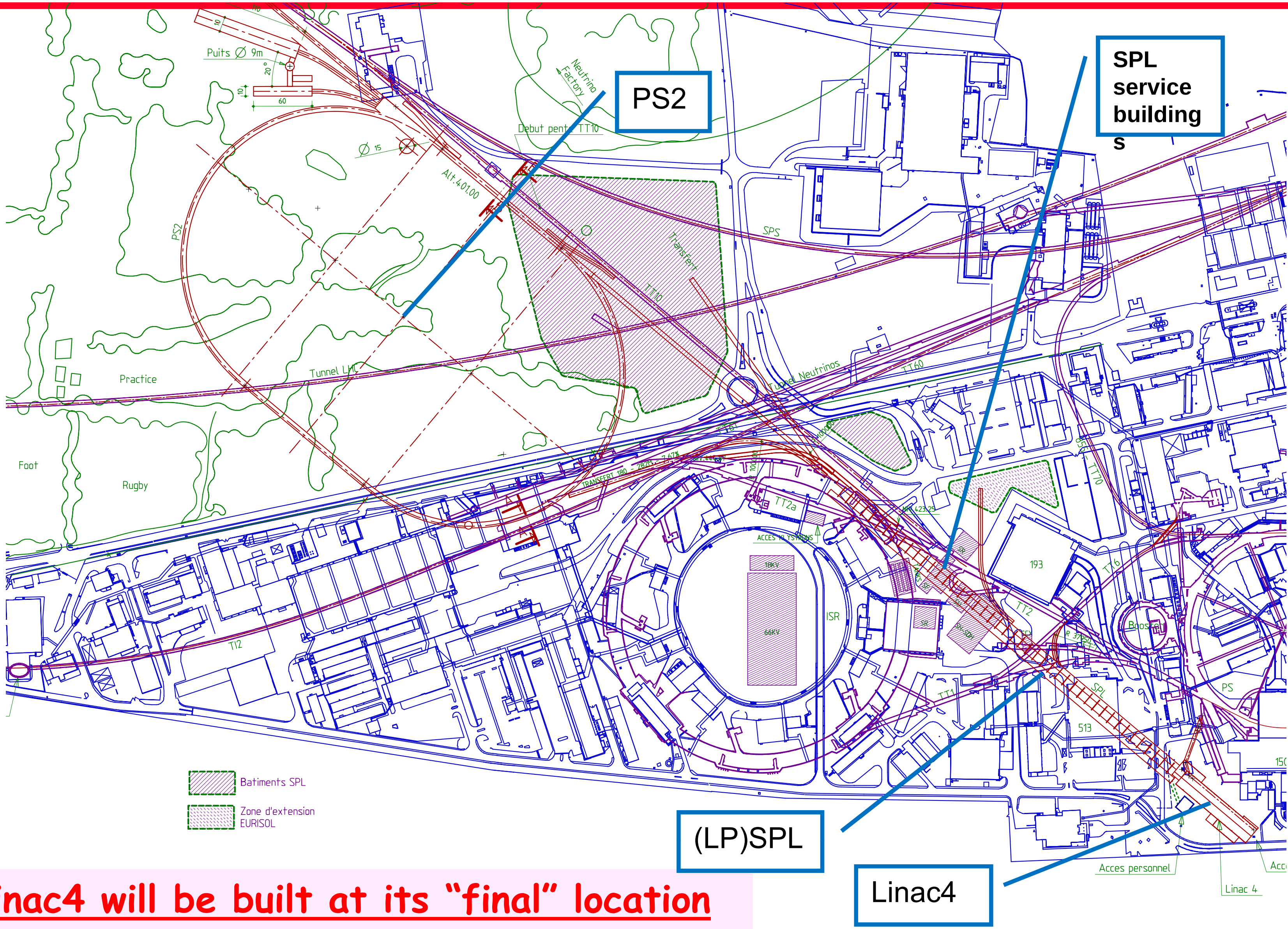
Expected benefits of the successive stages of upgrade for the LHC

STAGE	1	2	3
DESCRIPTION (*new accelerator*)	*Linac4* PSB PS SPS	*Linac4* *(LP)SPL* *PS2* SPS	*Linac4* *(LP)SPL* *PS2* *SPS+*
Characteristics of beam entering PS/PS2	~ Ultimate LHC beam in 1 PSB pulse instead of 2 >> Ultimate LHC beam in 2 PSB pulses	>2x ultimate LHC beam in 1 injection	- As in stage 3
Characteristics of beam entering SPS/SPS+	- 72 ultimate LHC bunches every 2.4s (instead of 3.6s) - Higher reliability (no long flat porch at PS injection) - Reduced injection flat porch (7.2s instead of 10.8s) - Possibility to study SPS limitation with brightness beyond ultimate	- Energy x2 (~50GeV) => improved SPS behaviour (farther from transition, reduced space-charge etc.) - Reduced injection flat porch (2.4s instead of 10.8s) - Highest reliability (no PS) - Capability to push the SPS to its maximum potential	- As in stage 3
Characteristics of beam entering LHC	- Capable of beam luminosity above nominal ($\geq 10^{34}$ cm^{-2}s^{-1}) - Higher reliability - Reduced filling time	- Beam characteristics for LHC luminosity upgrade (>> 2.5 10^{34} cm^{-2}s^{-1}) - Highest reliability - Minimum filling time	- As in stage 3 + - Energy x2 (~1 TeV) - Capability to push the LHC to its maximum potential - Adequate for DLHC

Expected benefits of the successive stages of upgrade for other CERN users

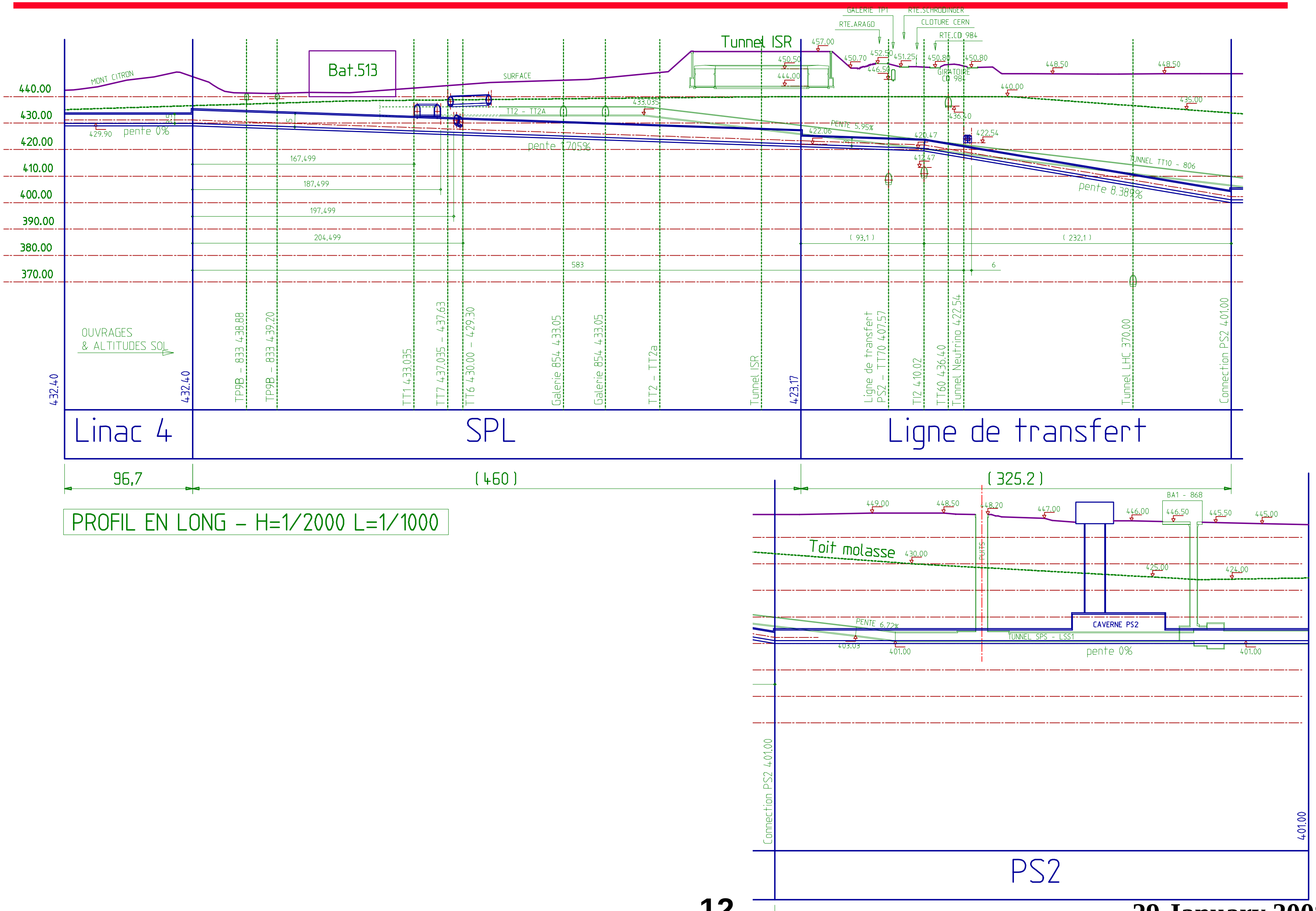
	STAGE		
	1	2	3
DESCRIPTION (*new accelerator*)	*Linac4* PSB PS SPS	*Linac4* *(LP)SPL* *PS2* SPS	*Linac4* *SPL* *PS2* SPS
β beam	**-**	**-**	**++ (γ~100)**
ν Factory	**-**	**-**	**+++ (~5 GeV prod. beam)**
k, μ	**-**	**~400 kW beam at 50 GeV**	**~400 kW beam at 50 GeV**
ISOLDE	**~double intensity**	**~ n times intensity**	**~ n times intensity**
EURISOL	**-**	**-**	**+++**

Layout of the new accelerators (1/2)



•**Linac4 will be built at its "final" location**

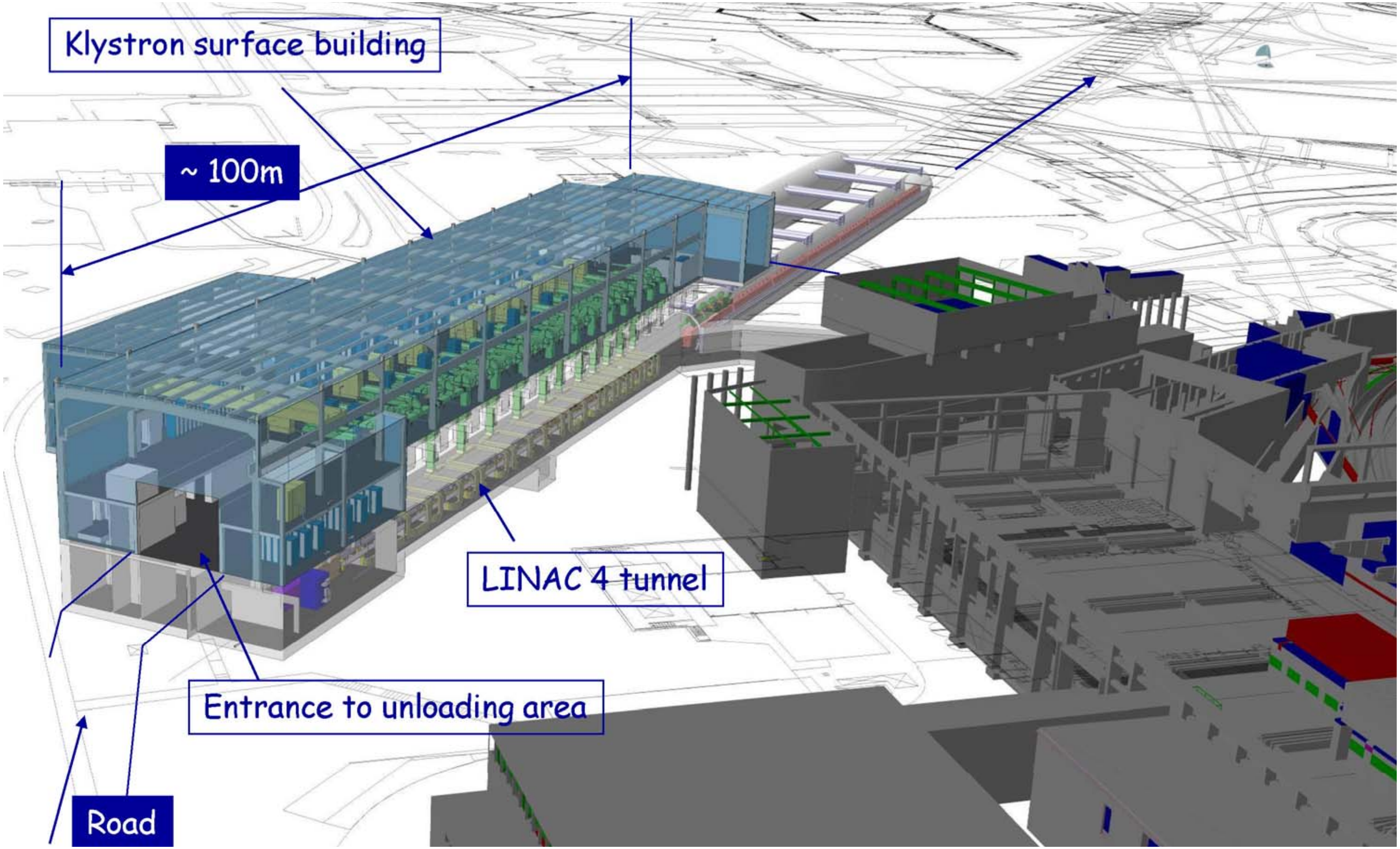
Layout of the new accelerators (2/2)



Linac4: main characteristics

Ion species	H^-
Output energy	160 MeV
Bunch frequency	352.2 MHz
Max. repetition rate	2 Hz
Beam pulse duration	0.4 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 p. pulse	$1.0\ 10^{14}$
Transverse emittance (source)	0.2 mm mrad
Transverse emittance (linac)	0.4 mm mrad

Linac4 building and infrastructure



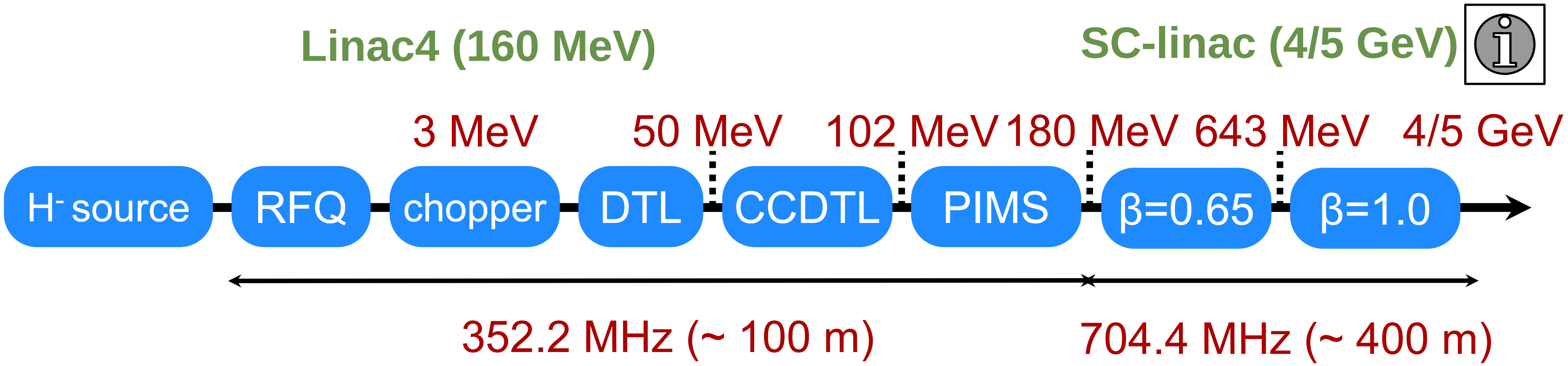
(LP)SPL: main characteristics

Stage		2	2'
	CDR2	"LPSPL" for SPS & LHC	"SPL"
Energy (GeV)	3.5	4	5
Beam power (MW)	4	0.19	4 - 8
Rep. frequency (Hz)	50	2	50
Protons/pulse (x 10^{14})	1.4	1.2	1
Av. Pulse current (mA)	40	20	40
Pulse duration (ms)	0.57	1.9	0.4
Bunch frequency (MHz)	352.2	352.2	352.2
Physical length (m)	430	~460	535

3 different designs:

- **CDR2 (CERN 2006-006) based on 700 MHz high-gradient cavities**
- **"LPSPL" for LHC (2007) with low beam power, for the needs of the LHC**
- **"SPL" at higher energy, for the needs of neutrino production and/or EURISOL**

(LP)SPL New Layout (CDR2, 2006)



New SPL Design (CDR2, CERN Yellow Report 2006-006):

Linac4 (extended to 180 MeV) + 2 superconducting sections based on 5-cell elliptical cavities at 704 MHz (INFN/CEA).

Long cryomodules (LHC/TESLA-like, 12-14m), 6-8 cav./module, cold quads in cryomodules

Overall length 430m (for 3.5 GeV, was 690m in previous version for 2.2 GeV)

	Medium β	*High* β
Cavity β	0.65	1
R/Q (Ohm)	235	575
Aperture (mm)	85	90
E_p/E_{acc}	2.6	2.4
E_{acc} (MV/m)	19	25

PS2: main characteristics

	PS2	PS
Injection energy kinetic (GeV)	4.0	1.4
Extraction energy kinetic (GeV)	~ 50	13/25
Circumference (m)	1346	628
Maximum intensity LHC (25ns) (p/b)	4.0×10^{11}	1.7×10^{11}
Maximum intensity for fixed target physics (p/p)	1.2×10^{14}	3.3×10^{14}
Maximum energy per beam pulse (kJ)	1000	70
Max ramp rate (T/s)	1.5	2.2
Repetition time at 50 GeV (s)	~ 2.5	1.2/2.4
Max. effective beam power (kW)	400	60

ROADMAP

Linac4 project

- **2007**
  - → mid-2007
    - Optimization of the layout on the CERN site
    - Negotiation of detailed work packages with external partners
    - CERN Council decision on the « White paper »
  - July → September 2007
    - Finalization of the design
    - Detailed Civil Engineering drawings
  - September → December 2007
    - Project organization inside CERN
- **2008: official start of the Linac4 project in January**
  - Project review
  - Start of Civil Engineering
  - Conclusion on allocation of work packages / distribution of « remaining » tasks inside CERN
  - Start of construction of Linac4 equipment
- **Mid-2011**
  - Progressive beam commissioning of Linac4
- **Mid-2012**
  - PSB stop for modification
  - PSB beam commissioning
- **Beginning 2013: PSB operational for physics with Linac4**

Site approved. Detailed drawings in progress

Yes !

In place

Organised in January 29-30

mid-2008

mid-2008

mid-2008

Preparation for the SLHC

- → **2011 for LHC and SPS**
  - **Selection of the most promising scenarios for the LHC upgrade**
  - **Experience with the LHC and its practical limitations…**
  - **Detailed technical design of the LHC upgrade**
  - **Detailed technical design of the SPS upgrade**
  - **Prototyping of critical components**
  - **Detailed estimates of the necessary resources**
  - **Negotiation with external contributors**

- → **2011 for the injectors of SPS**
  - **Optimization of the layout on the CERN site**
  - **Optimization of compatibility with other users (EURISOL, ν's, pbars, heavy ions…)**
  - **Detailed technical design**
  - **Prototyping of critical components**
  - **Detailed Civil Enginering drawings**
  - **Detailed estimates of the necessary resources**
  - **Negotiation with external contributors**

→ publication of Technical Design Reports with resources estimates

Implementation of the LHC luminosity upgrade

- **2012 → 2017 for LHC and SPS**
  - Construction of components for the LHC and SPS upgrade
  - Progressive modification of the SPS (vacuum chamber treatment, impedance reduction etc.)

- **2012 → 2017 for the injectors of SPS**
  - Construction of LPSPL and PS2
  - Progressive beam commissioning of LPSPL
  - Beam commissioning of PS2

- **2017**
  - Connection of PS2 to SPS & final modifications of the SPS (injection system etc.)
  - Beam commissioning of the SPS
  - Beam commissioning of the LHC

CONCLUSION

- ✓ **CERN is soon going to commission the largest and most sophisticated particle accelerator ever built. Such an installation must be fully exploited.**
  - ⇒ **It is time to prepare for securing its operation, increasing the reliability of all the infrastructure for protons and ions.**
  - ⇒ **It is time to develop solutions for pushing performance to the limit.**

- ✓ **Linac4 is a first step towards the replacement of many of the "old" low and medium accelerators that have faithfully served physics <u>during half a century!</u>**

- ✓ **Our duty is to do our best to provide HEP with accelerators having a potential of evolution similar to the machines they will replace.**

Thank you for your help!

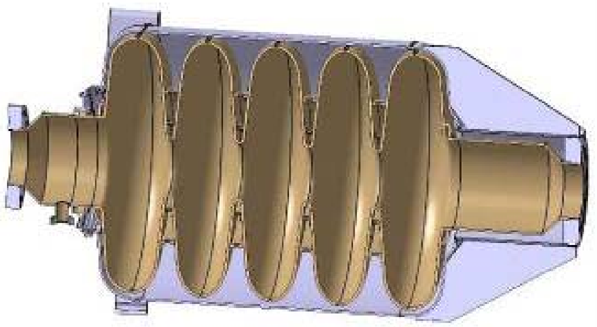
REFERENCES

(LP)SPL and PS2: benefits

- **Direct benefits of the LPSPL + PS2**
  - **Stop of PSB and PS:**
    - End of recurrent problems (damaged magnets in the PS, etc.)
    - End of maintenance of equipment with multiple layers of modifications
    - End of operation of old accelerators at their maximum capability
    - Safer operation at higher proton flux (adequate shielding and collimation)
  - **Higher performance:**
    - Capability to deliver 2.2$\times$ the ultimate beam for LHC to the SPS
      => potential to prepare the SPS for supplying the beam required for the SLHC,
    - Higher injection energy in the SPS + higher intensity and brightness
      => easier handling of high intensity. Potential to increase the intensity per pulse.

- **Benefits for users of the LPSPL and PS2**
  - More than 50 % of the LPSPL pulses will be available (not needed by PS2)
    => New nuclear physics experiments – extension of ISOLDE (if no EURISOL)…
  - Upgraded characteristics of the PS2 beam wrt the PS (energy and flux)
  - Potential for a higher proton flux from the SPS

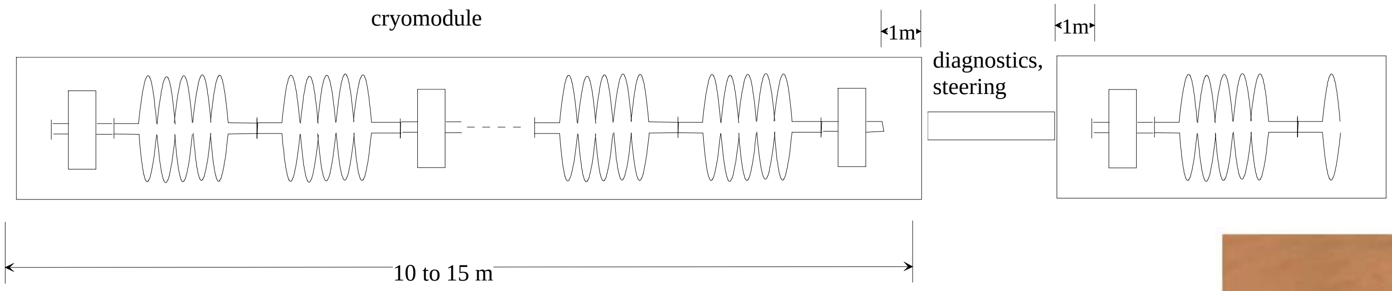
(LP)SPL cavities: elliptical, 704 MHz



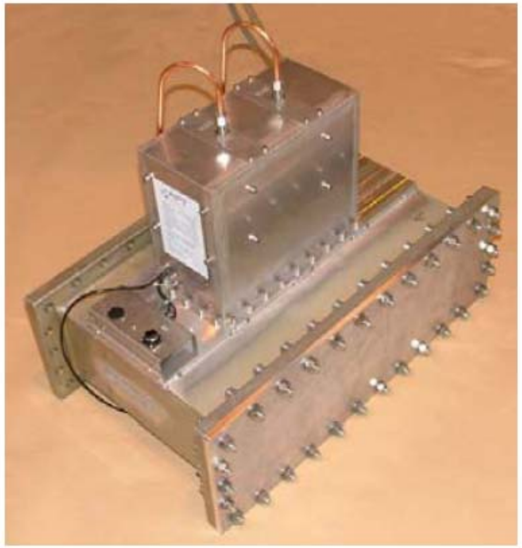
Elliptical cavities at β=0.5 (CEA, INFN) are giving promising results. Stiffened for pulse operation.

Length ~ 0.9m

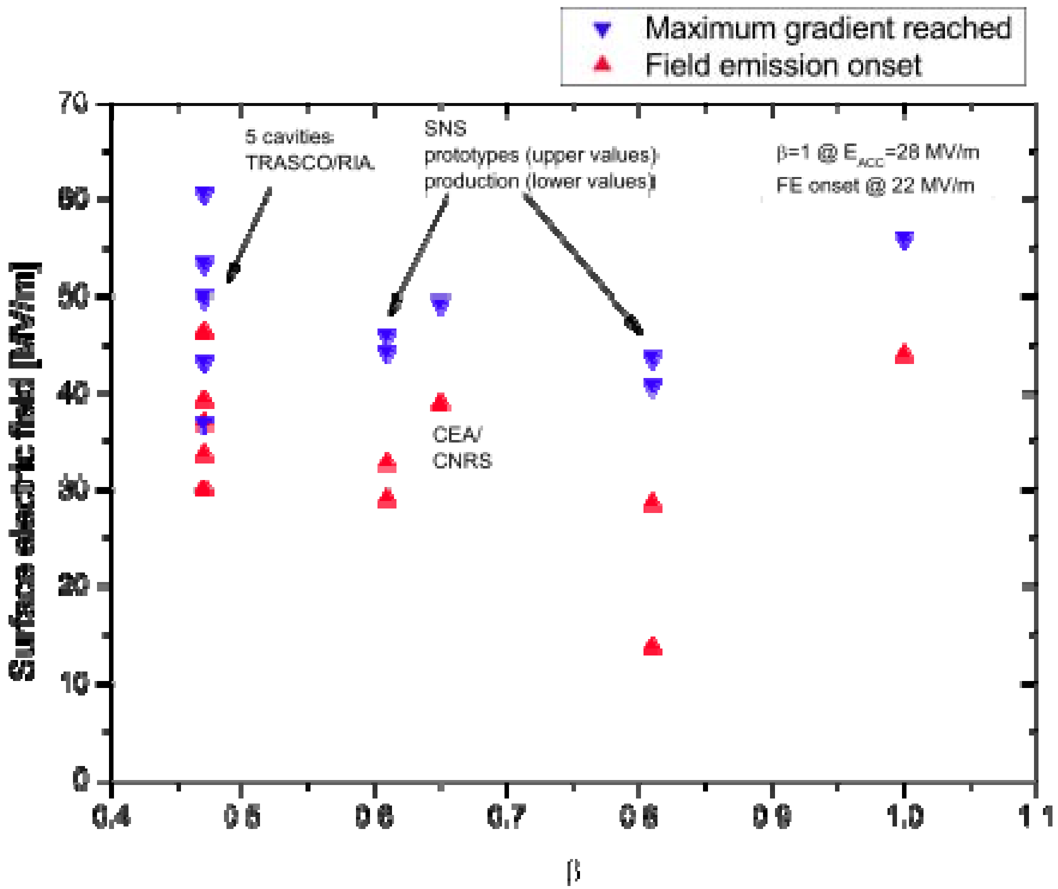
Designed for 12 MV/m.



* Feed 4 to 6 cavities per klystron: use high power phase and amplitude modulators.

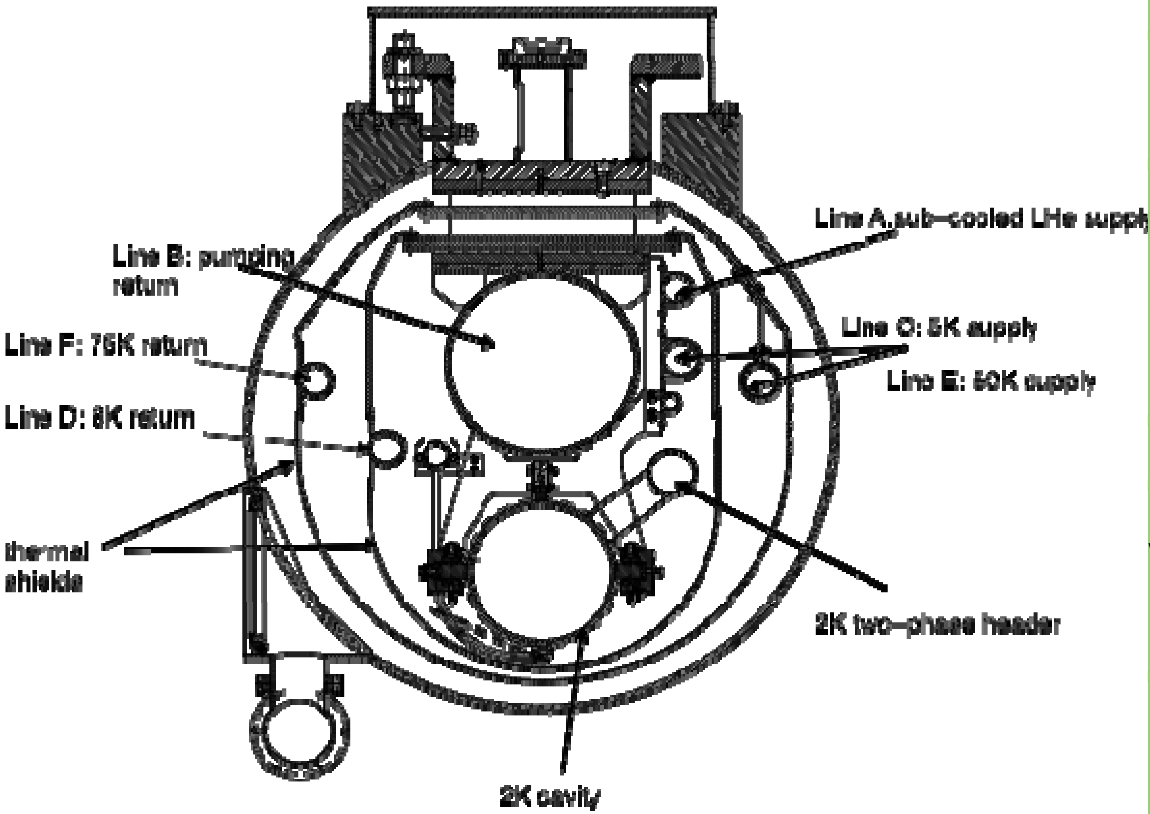


(LP)SPL accelerating gradient



- maximum surface fields for SPL cavities are based on measured cavity performance (CW operation),
- surface fields: 50 MV/m and 100 mT are challenging but seem realistic for pulsed operation,
- chosen gradients for β=0.65/1 >> 19/25 MV/m,

(LP)SPL cryostats



- based on the TESLA/ILC approach,
- long cryo-modules (11.45/14.26 m) with low static losses, low number of cold/warm transitions,
- cold quadrupoles,
- difficult to repair (e.g. when compared with SNS), but hopefully less leaks,
- long time for development and prototype testing!!

Vertical cross section L-L of SPL tunnel