The SPL

1. Introduction
2. Description
   - Technology & basic parameters
   - Architecture & beam characteristics
3. Possible options
4. Final words

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SPL

1. Introduction

Motivation for new injectors

1. Reliability ↑

The present accelerators are getting old (PS is 50 years old !) and they operate far beyond their initial design parameters

⇒ need for new accelerators designed for the needs of SLHC

2. Performance ↑

Brightness N/ε^* of the beam in LHC must be increased beyond the capability of the present injectors to allow for phase 2 of the LHC upgrade. [Excessive incoherent space charge tune spreads ΔQ_{SC} at injection in the PSB and PS].

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

with N_b : number of protons/bunch

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

R : mean radius of the accelerator

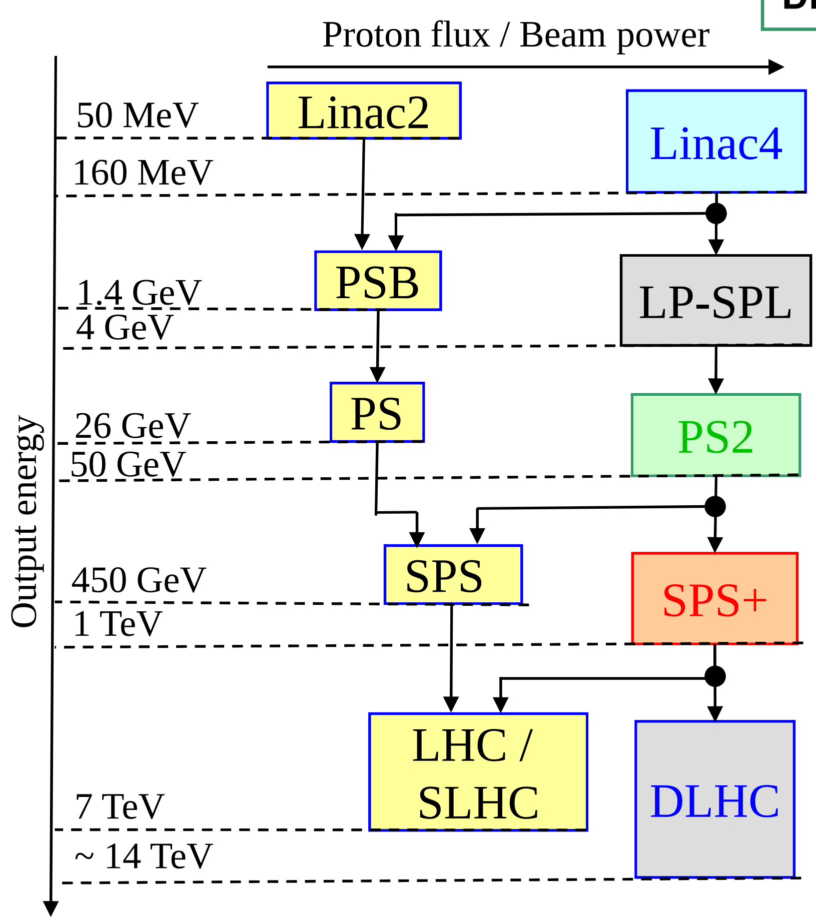
$\beta\gamma$: classical relativistic parameters

⇒ need to increase the injection energy in the synchrotrons

- **Increase injection energy in the PSB from 50 to 160 MeV kinetic**
- **Need for 4 GeV injection energy in PS2 (PS successor) to allow for 2.2 times the ultimate beam brightness in SLHC**
- **Increase injection energy in the SPS from 25 to 50 GeV kinetic (partly because of space charge, but mostly to inject further from transition energy and to displace TMCI threshold)**

Present and future accelerators

LP-SPL: Low Power-Superconducting Proton Linac (4 GeV)
PS2: High Energy PS (~ 5 to 50 GeV – 0.3 Hz)
SPS+: Superconducting SPS (50 to1000 GeV)
sLHC: "Super-luminosity" LHC (up to 10^{35} $cm^{-2}s^{-1}$)
DLHC: "Double energy" LHC (1 to ~14 TeV)



Main requirements of PS2 on its injector:

Requirement	Parameter	Value
2.2 x ultimate brightness with nominal emittances	Injection energy	4 GeV
	Nb. of protons / cycle for LHC (180 bunches)	6.7×10^{13}
Single pulse filling of SPS for fixed target physics	Nb. of protons / cycle for SPS fixed target	1.1×10^{14}

Comparison LP-SPL / RCS

Summary table comparing:
- RCS (10 Hz) filling PS2 in 14 pulses (1.3 s) + multiple gymnastics in PS2
- LP-SPL (2Hz) filling PS2 in 0.6 ms + no gymnastics in PS2

	Filling time PS2	Time structure for LHC	Relative proton rate	Fixed target physics	Heavy Ions	Upgrade potential	Relative Cost[1]
LP-SPL	0.6ms	inherent	2.5	ideal	OK	high	1.28
RCS	1.3s	different	1	OK	ideal	low	1
Advantage	**SPL**	**SPL**	**SPL**	**SPL**	**RCS**	**SPL**	**RCS**

[1] The relative cost considers only the items that differ between both options

⇓

The LP-SPL is the best solution for the LHC and it offers a large upgrade potential for the future needs of physics.

Ref.: Comparison of Options for the Injectors of PS2, CERN-AB-2007-014 (PAF), http://cdsweb.cern.ch/record/1029954/files/ab-2007-014.pdf

Goal of the SPL study (2008-2012)

from Note on 31/03/2009 (EDMS Id 993472)

The goal of the SPL study is to prepare for a start of construction of the low power SPL optimized for PS2 and LHC at the beginning of 2013.

For that purpose, a detailed Conceptual Design Report and a cost estimate will be published in May 2012. The cost of leaving the possibility of a later upgrade to 5 GeV and high beam power will also be quantified.

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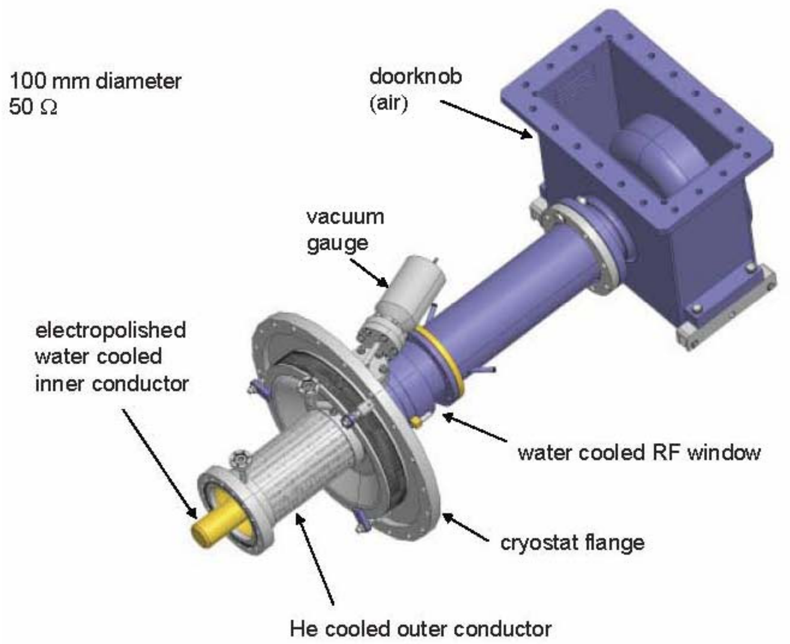
2. Description

Technology [1/2]

Elliptical 5 cell bulk Niobium cavities
(e.g.: β=0.47)

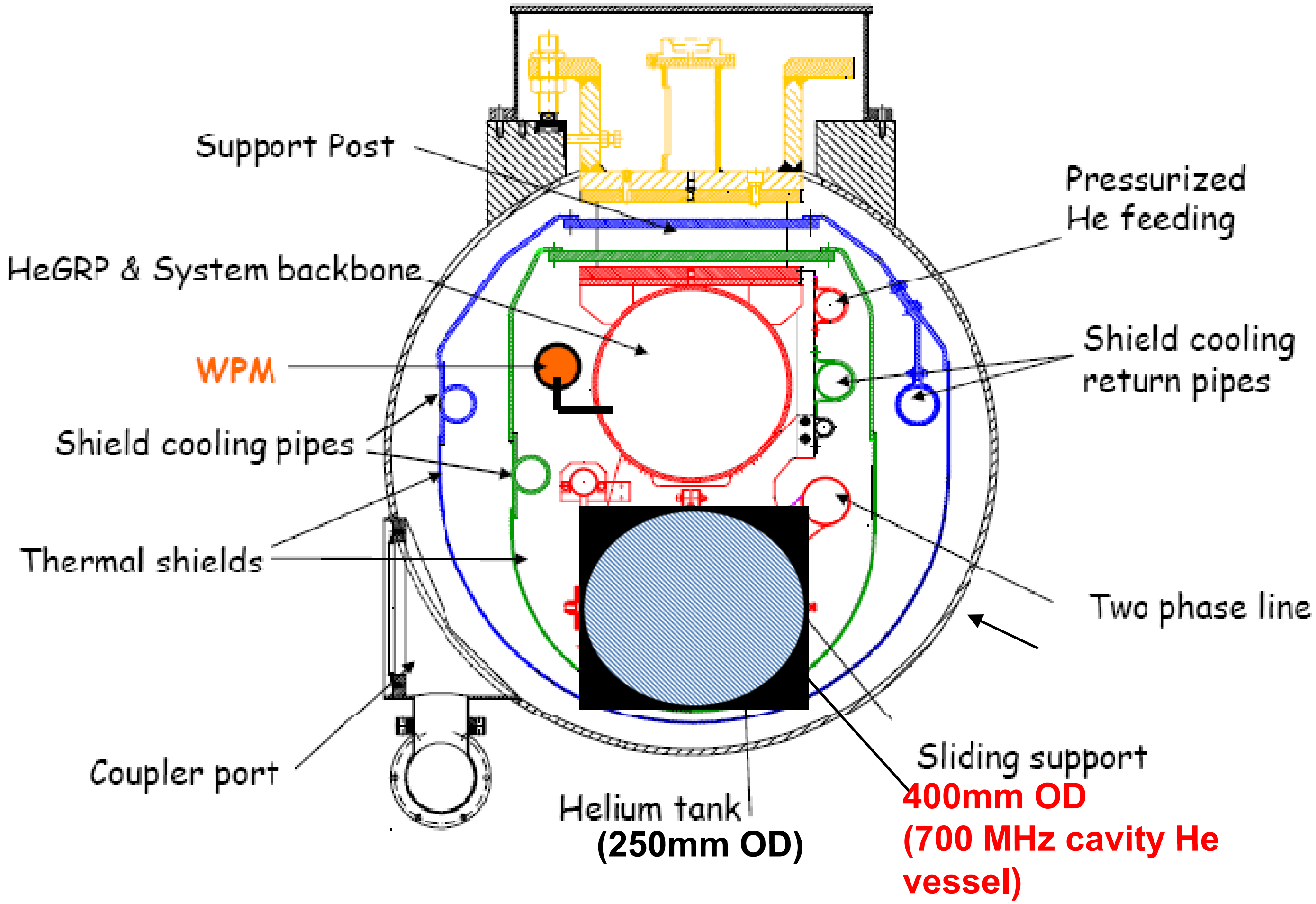
Auxiliary equipment
(e.g.: 1 MW RF coupler)



from G. Devanz – HIPPI meeting Nov. 2007)

Technology [2/2]

“Typical” cryomodule (TTF III)



Parameters: RF frequency [1/3]

Frequency	704 MHz	1408 MHz
Length (5 GeV)	472 m	+12%
$N_{cavities}$	246	+15%
$N_{\beta\text{-families}}$	2	3
ε-growth (x/y/z)	5.6/8.2/6.8	6.3/7.8/12.1
Longitudinal beam loss	none in simulations	lossy runs for realistic RF gradient/phase variations
BBU (HOM)	$I_{BBU,704}$	1/(8..128)
Trapped modes	normal risk	2..4 higher risk
RF power density limit (RF distribution)	ok	problematic
Klystrons	comfortable: MBK	difficult
Overall power consumption (RF+cryo, nom. SPL)	28 MW	up to -30%
Power converter	more bulky	saves tunnel space
Synergy with ESS	yes	no

Parameters: Cooling temperature [2/3]

@ 704 MHz	T [K]	Eq. capacity @ 4.5 K [kW]	Electrical power [MW]
HP-SPL, 2% beam d.c. (4% cryo d.c.)	2	19.4	4.48
HP-SPL, 2% beam d.c. (4% cryo d.c.)	4.5	104	26.0
LP-SPL, 0.24% beam d.c. (0.32% cryo d.c.)	2	6.1	1.5
LP-SPL, 0.24% beam d.c. (0.32% cryo d.c.)	4.5	11	2.75

+ not clear that 25 MV/m can be achieved at 4.5 K!

Parameters: Summary [3/3]

Frequency/temperature:

704 MHz and 2 K are confirmed,

Cavity gradient:

- 25 MV/m "on average" (= with a high yield) is very challenging and may be costly (in terms of reprocessing),
- 20 MV/m seems more achievable but will have an impact on linac length (or energy).

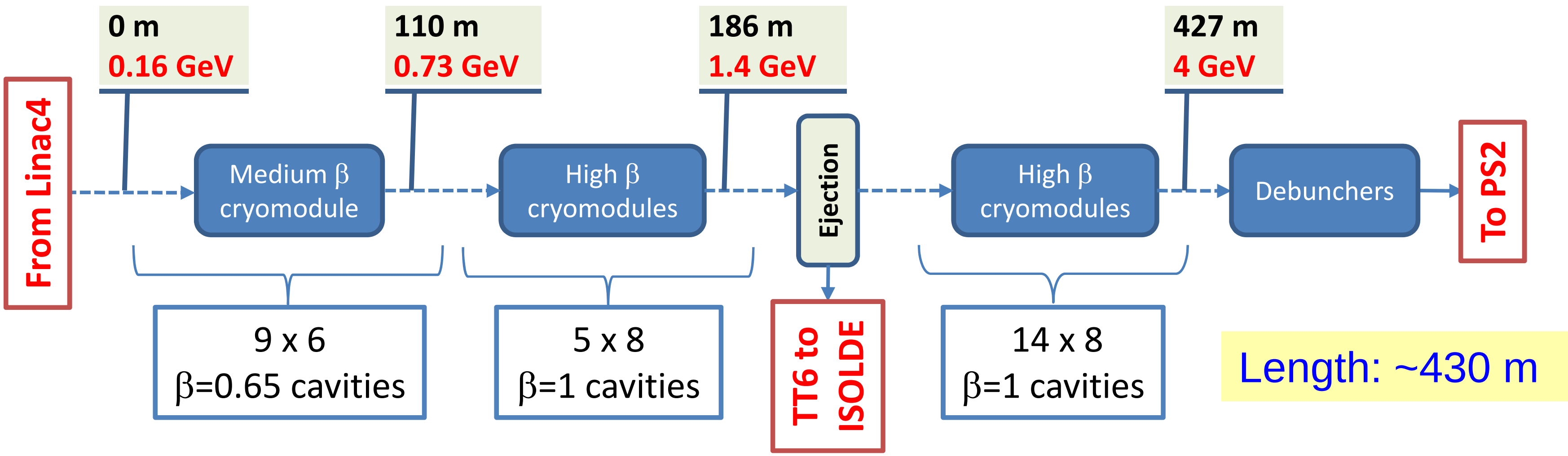
⇓

High-power RF cavity tests of fully equipped cryo-modules are mandatory for realistic SPL layout estimates!!

Ref.: Assessment of the basic Parameters of the CERN SPL, CERN-AB-2008-067-BI-RF, http://cdsweb.cern.ch/record/1136901/files/CERN-AB-2008-067.pdf

Architecture [1/3]

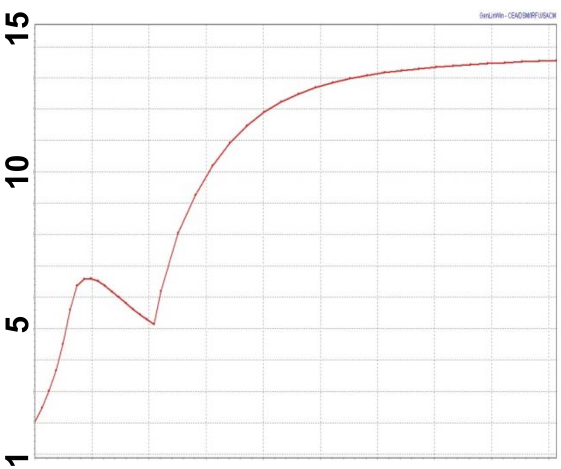
SC-linac (160 MeV → 4 GeV) with ejection at intermediate energy



LP-SPL beam characteristics at 4 GeV

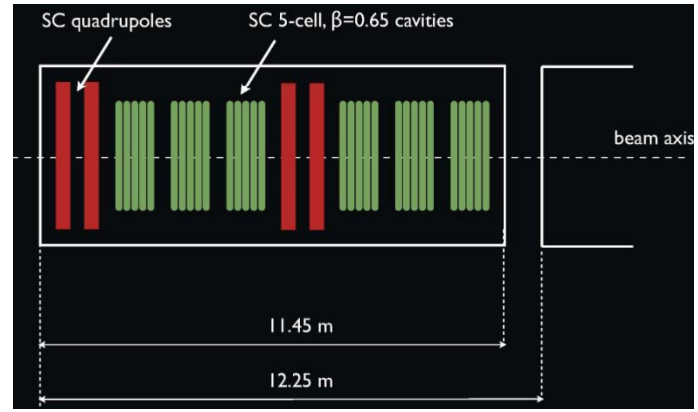
Kinetic energy (GeV)	4
Beam power at 4 GeV (MW)	0.12
Repetition period (s)	0.6
Protons/pulse (x 10^{14})	1.1
Average pulse current (mA)	20
Pulse duration (ms)	0.9

Architecture [2/3]



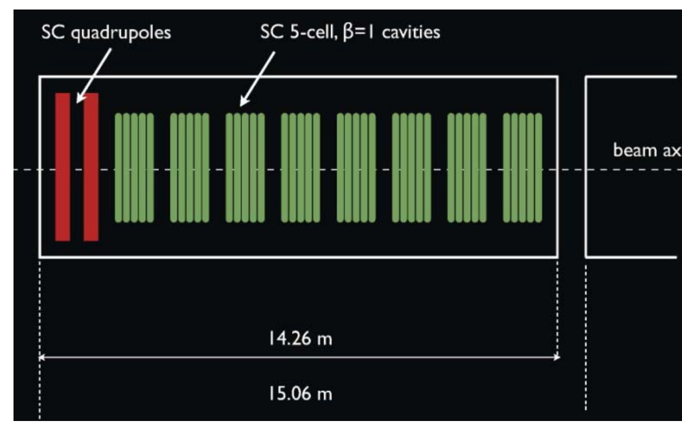
Medium β cryomodule

Energy range: 160 MeV – 732 MeV
5 cell cavities
Geometrical β: 0.65
Maximum energy gain: 19.4 MeV/m
54 cavities (9 cryomodules)
Length of medium β section: ~110.35 m

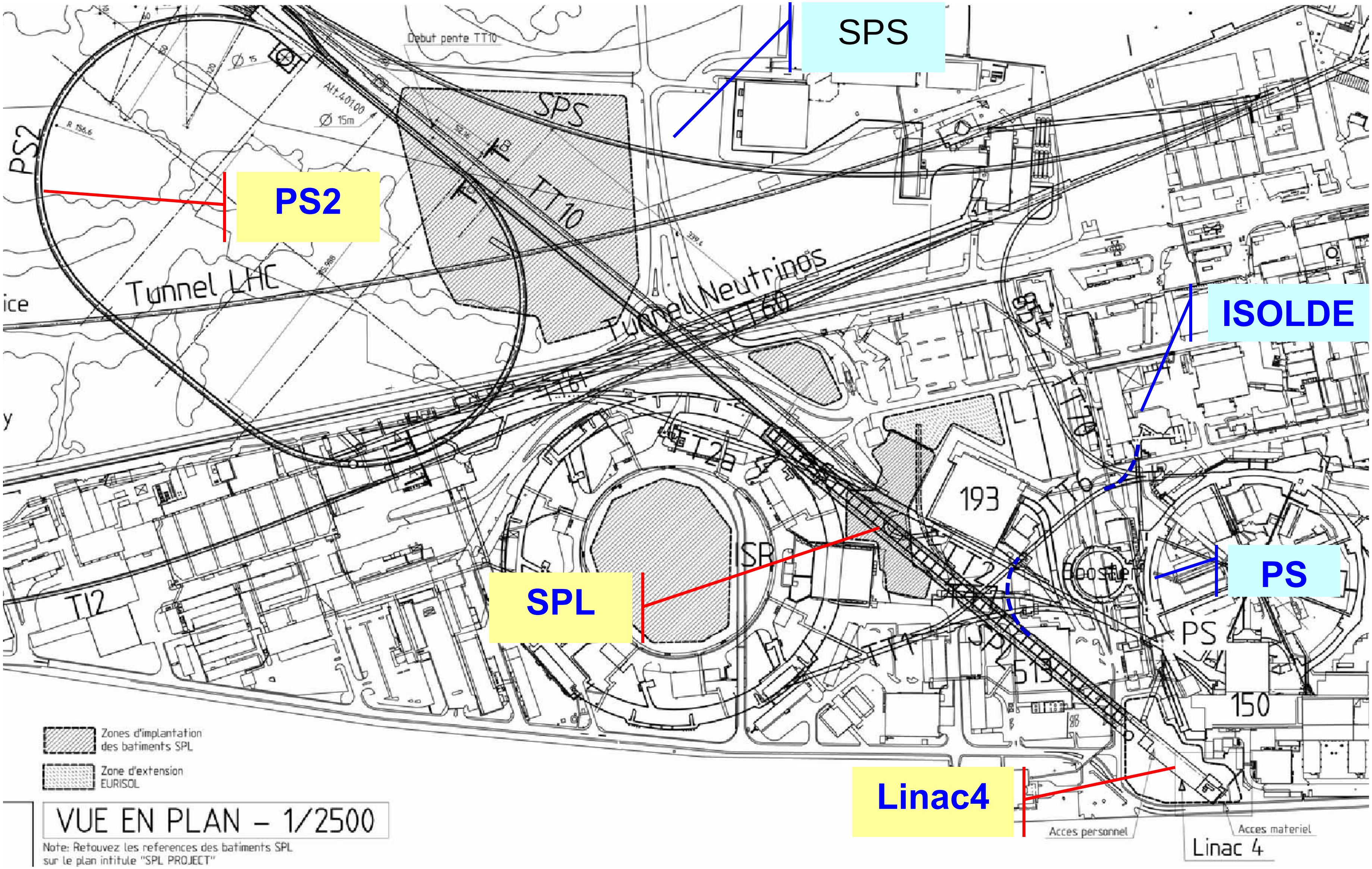


High β cryomodule

Energy range: 732 MeV – 4 GeV
5 cell cavities
Geometrical β: 1
Maximum energy gain: 25 MeV/m
152 cavities (19 cryomodules)
Length of medium β section: ~286.2 m



Architecture [3/3]



LP-SPL beam characteristics for ISOLDE

	Beam energy (GeV)	Max. pulse duration (ms)	Max. current during pulse (mA)	Repetition period (s)	Max. protons /pulse ($x10^{13}$)	Max. beam power (kW)
PS2	4	0.9	20	0.6	11	120
Basic performance	1.4	0.9	20	~ 0.6 (3 out of 4 pulses)	11	31
ISOLDE		0.35	28	~ 0.3 (7 out of 8 pulses)	6.1	29
Need phase modulation		0.35	28	~ 0.1 (23 out of 24 pulses)	6.1	94

Needs higher power klystron modulators

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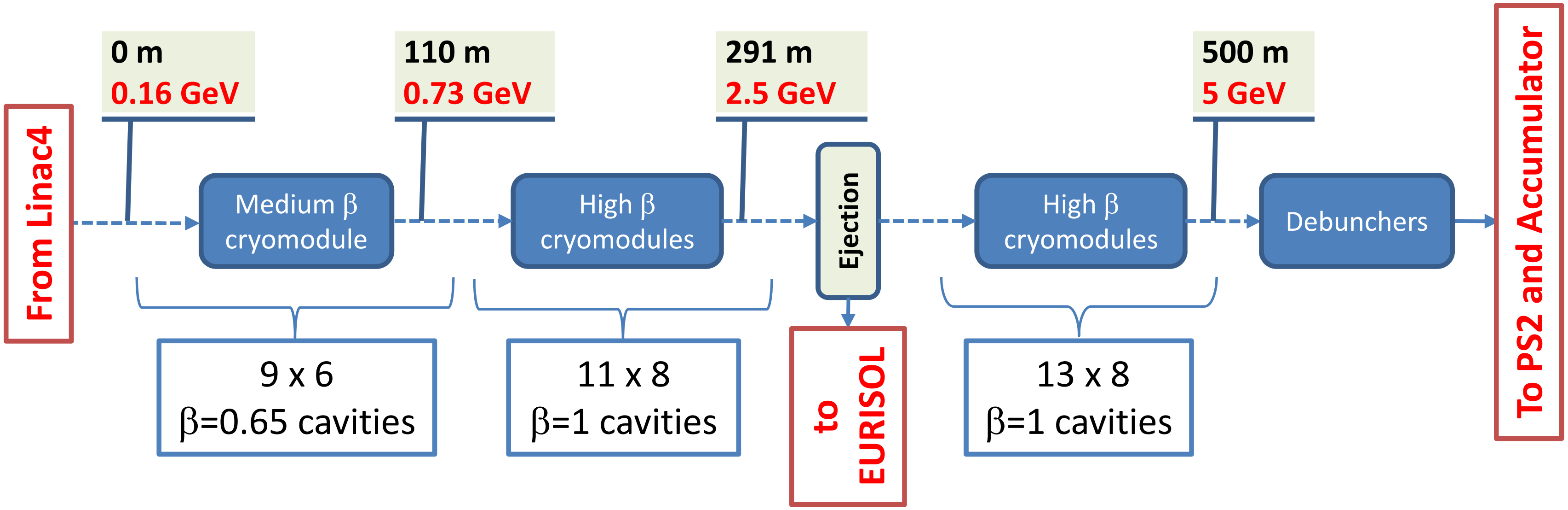
3. Possible options

High Power proton beams (HP-SPL) [1/2]

- Replacement of klystron power supplies, upgraded infrastructure (cooling & electricity, etc.)
- Addition of 5 high β cryomodules to accelerate up to 5 GeV (π production for ν Factory))

SC-linac (160 MeV → 5 GeV) with ejection at intermediate energy



Length: ~500 m

High Power proton beams (HP-SPL) [2/2]

Beam characteristics of the main options

	Option 1	Option 2
Energy (GeV)	2.5 or 5	2.5 and 5
Beam power (MW)	2.25 MW (2.5 GeV) <u>or</u> 4.5 MW (5 GeV)	4 MW (2.5 GeV) <u>and</u> 4 MW (5 GeV)
Rep. frequency (Hz)	[redacted]	
Protons/pulse (x 10^{14})	1.1	2 (2.5 GeV) + 1 (5 GeV)
Av. Pulse current (mA)	20	[redacted]
Pulse duration (ms)	0.9	0.8 (2.5 GeV) + 0.4 (5 GeV)

Faster rep. rate $\Rightarrow$ new power supplies, more cooling etc.

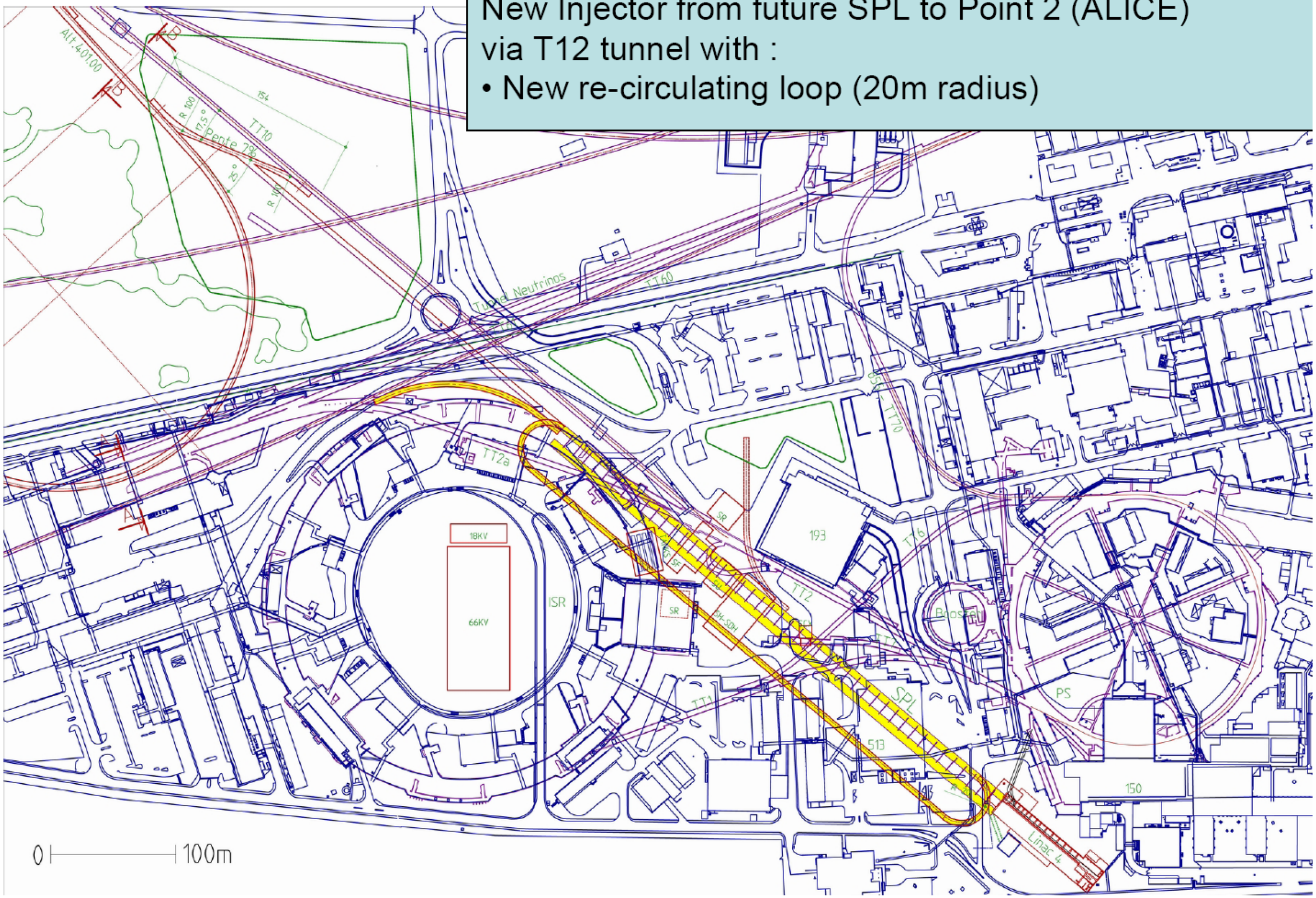
2 $\times$ beam current $\Rightarrow$ 2 $\times$ nb. of klystrons etc .

e+/e- acceleration

LHeC: 20 GeV e+/e- from the SPL (5-pass acceleration in the β=1 section) as a pre-injector for a lepton ring in the LHC tunnel (Ring/Ring option)

New Injector from future SPL to Point 2 (ALICE) via T12 tunnel with :

- New re-circulating loop (20m radius)



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4. Final words

Highlight from my talk:

- The LP-SPL is well matched to the needs of CERN:
  - It is the best solution for proton injection in LHC,
  - It has a large upgrade potential for non-LHC applications.
- A rational layout has been defined which optimizes high energy applications and remains compatible with multiple low/medium energy uses.

Additional comments:

- Technological developments and prototyping are necessary during the next years to prepare a consistent project proposal by mid-2012. Strong synergy with other similar projects (ESS, Project-X, ADS…) should help reduce cost.
- Planning is tight…

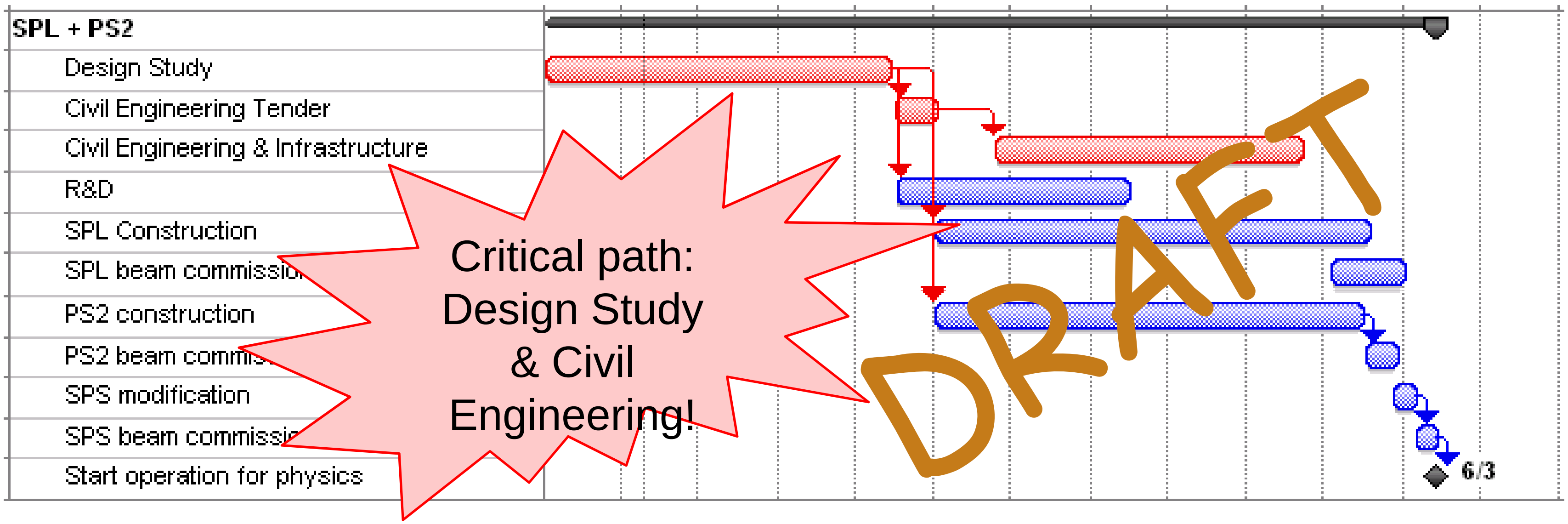
THANK YOU
FOR YOUR ATTENTION!

Planning

Implementation of the new injectors:
LP-SPL + PS2

Construction of LP-SPL and PS2 will not interfere with the regular operation of Linac4 + PSB for physics.

Similarly, beam commissioning of LP-SPL and PS2 will take place without interference with physics.

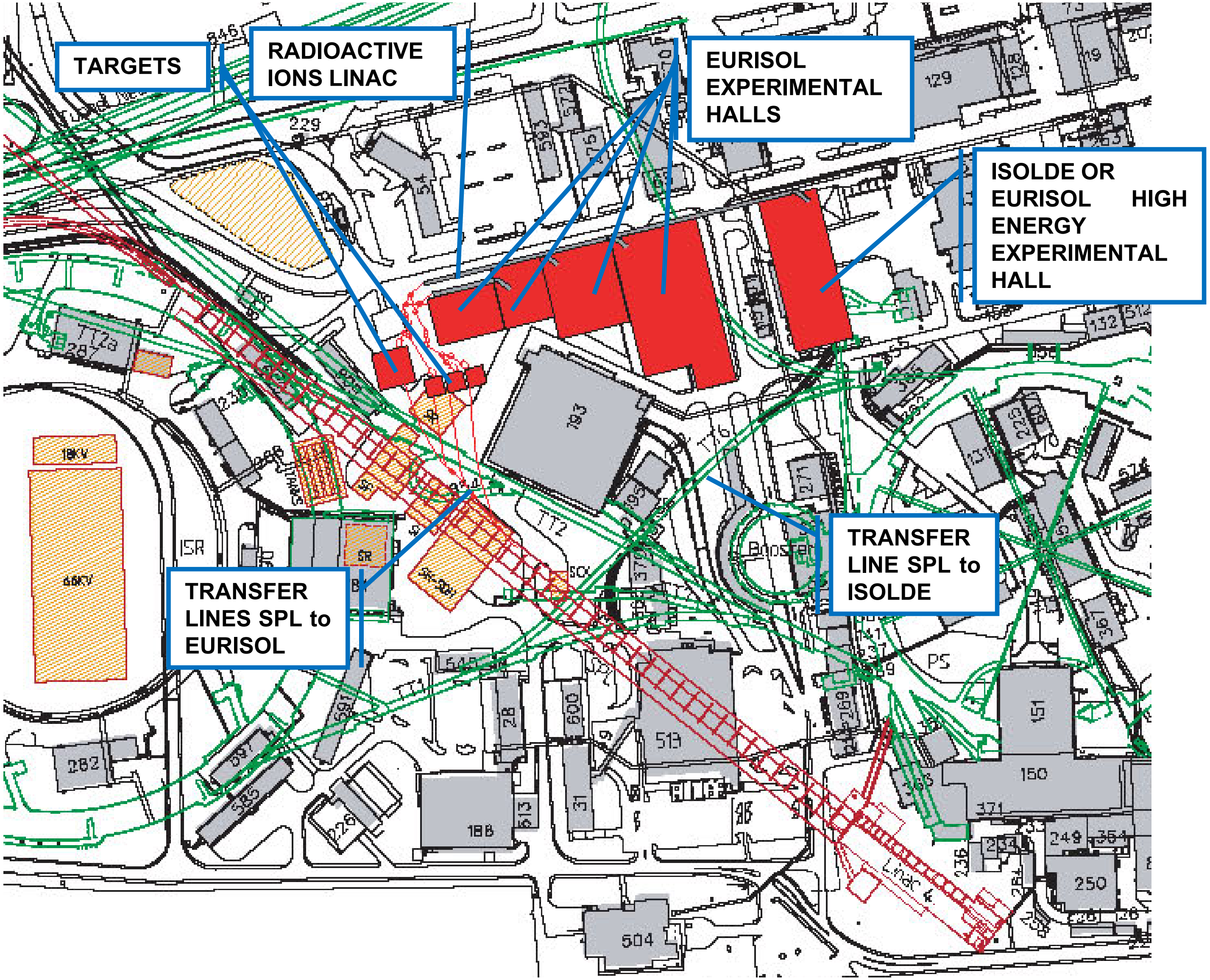


First milestones

- Project proposal: 2011- 2012
- Project start: January 2013

High power proton applications

ISOLDE & EURISOL



Neutrino Factory