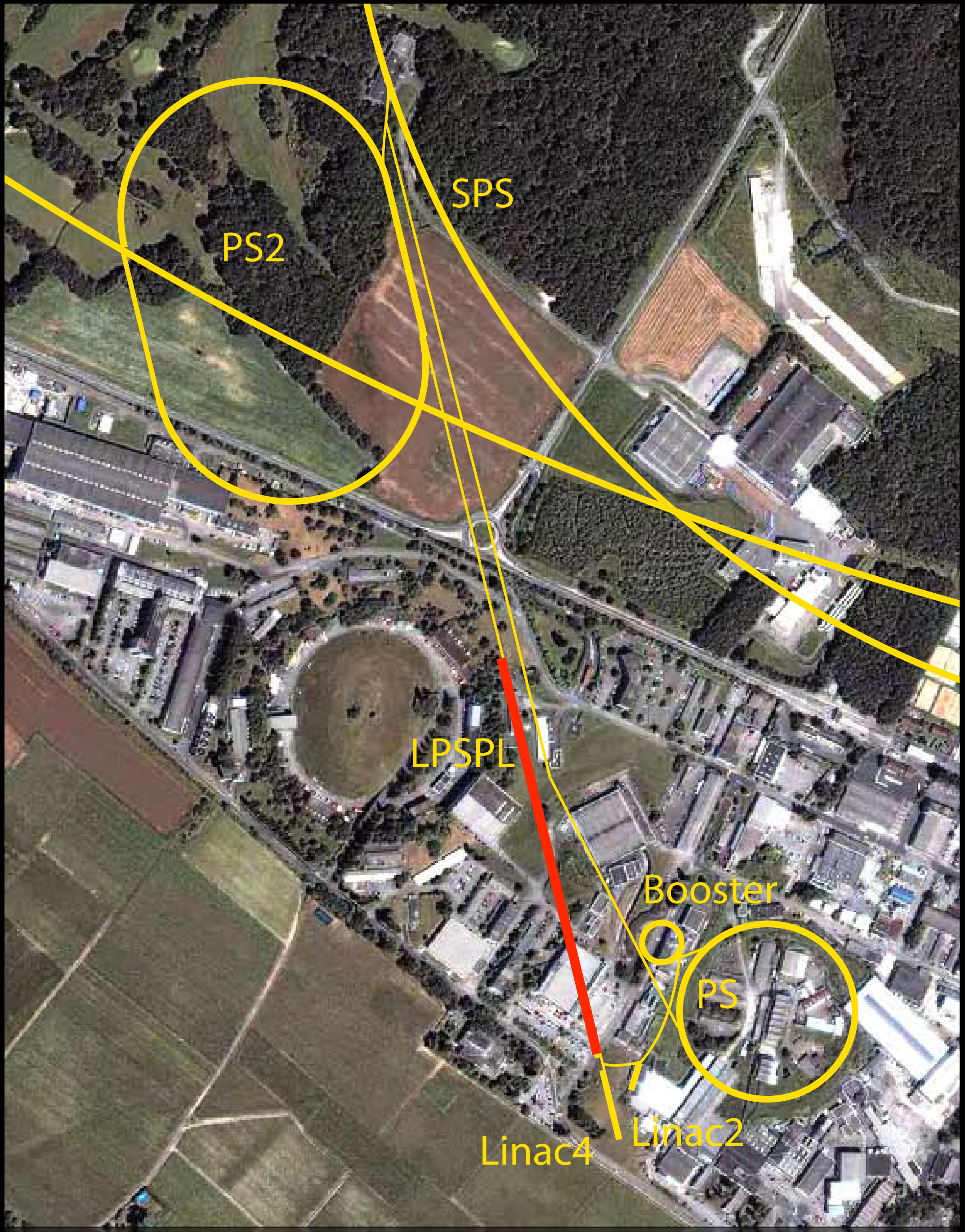
SPL, project & status

F. Gerigk for the SPL study group

SLHC public event, 26.02.2009



http://www.cern.ch/project-spl

Outline

- motivation,
- staged implementation,
- political/technical milestones:
  - ➡ comparison SPL/RCS,
  - ➡ site decision,
  - ➡ parameter review,
  - ➡ start of SPL collaboration,
- R&D status,
- planning,

motivation to renew the injector chain

1.) reliability:

- ageing accelerators operate far beyond initial specifications (PS is 48 years old!),

➡ use present day technology to meet the needs of the (S)LHC,

2.) overcome performance limitation:

- excessive incoherent space charge tune shift (ΔQ_{SC}) at injection into PSB/PS,

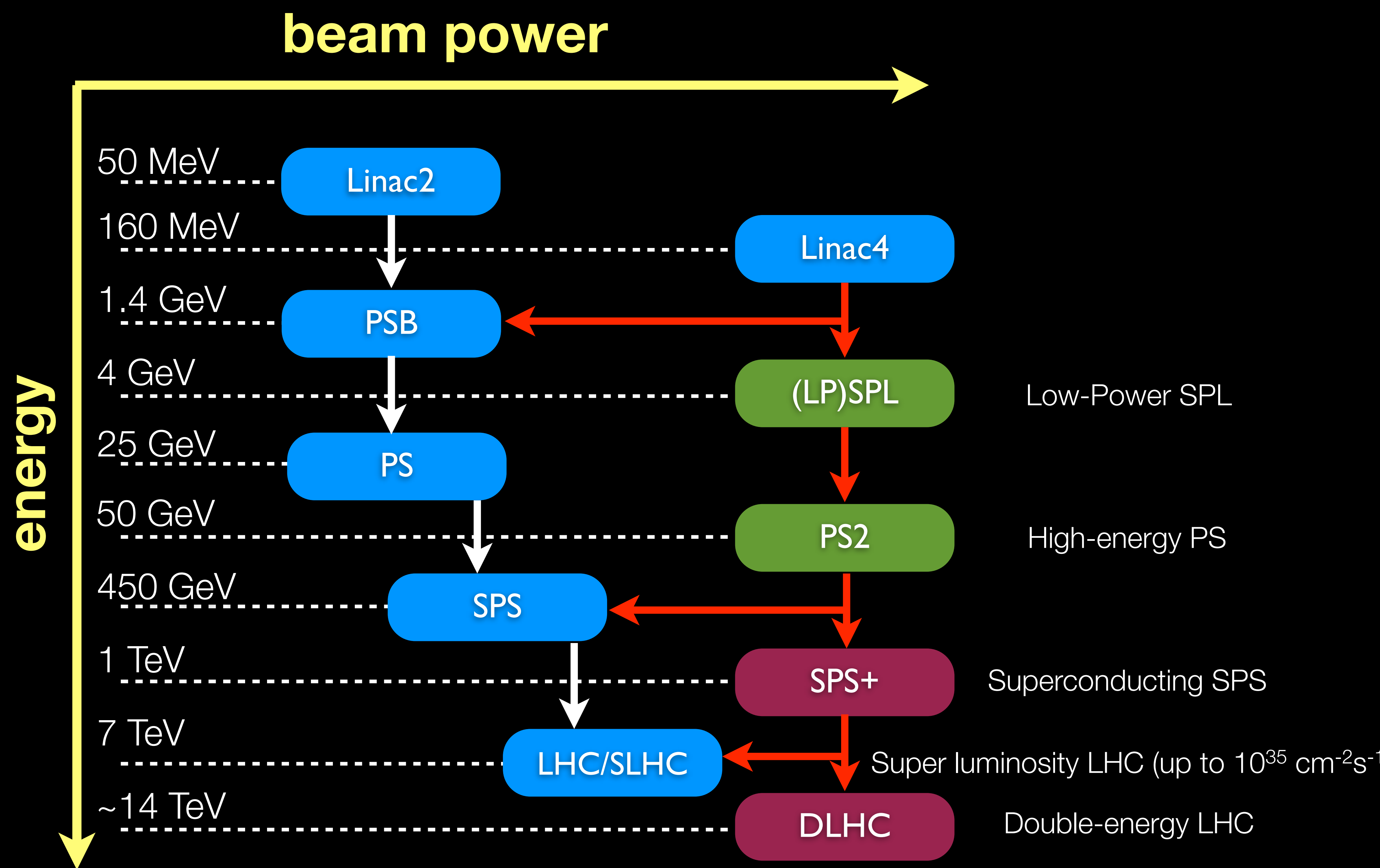
➡ increase injection energy into PSB from 50 ➜ 160 MeV: **Linac4** *(reduces ΔQ_{SC} by 50%)*,

➡ increase injection energy into **PS2** from 1.4 to 4 GeV: **SPL**, *(acceptable ΔQ_{SC} for maximum foreseen SLHC beam)*,

➡ increase injection energy into SPS from 25 to 50 GeV: **PS2**,

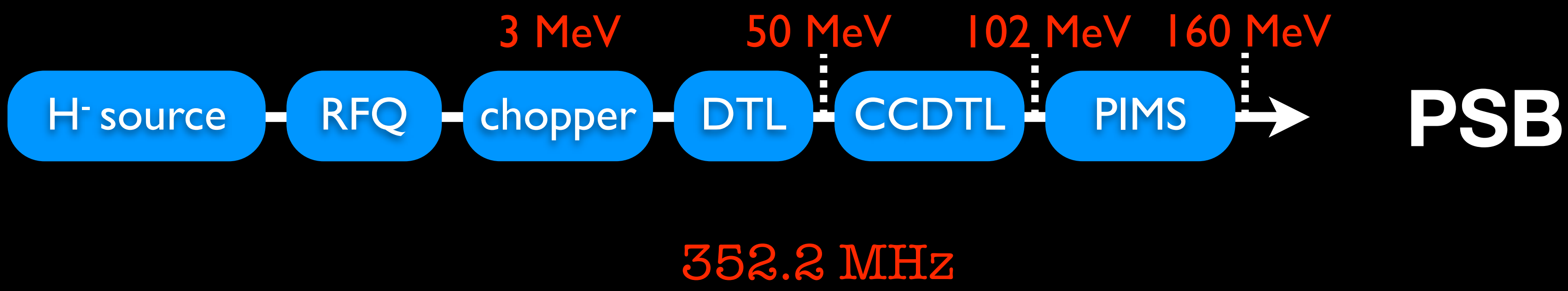
$$\Delta Q_{SC} \propto \frac{N_b}{\varepsilon_{x,y}} \cdot \frac{R}{\beta\gamma^2} \qquad N_b - \mathrm{p/bunch},\ \varepsilon_{x,y} - \mathrm{norm.\ tr.\ emittances},\ R - \mathrm{mean\ synchr.\ rad.},\ \beta\gamma - \mathrm{rel.\ par.}$$

LHC injector upgrade (R. Garoby)



SPL construction, stage 1:

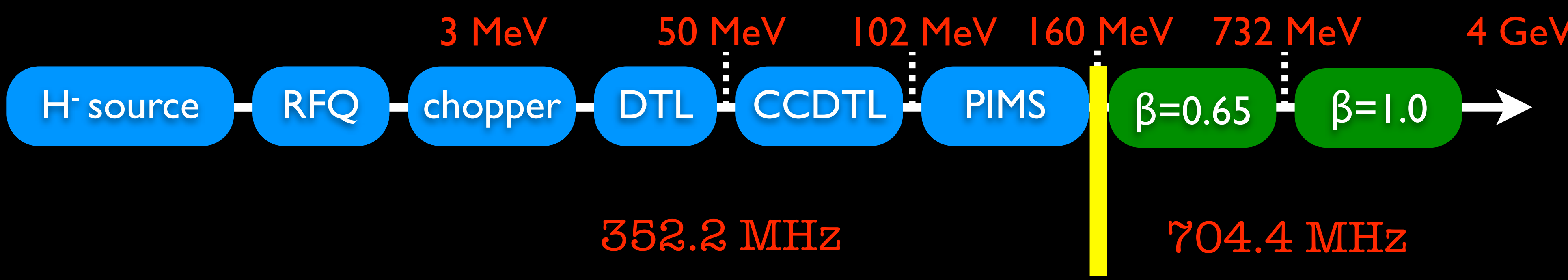
Linac4 (160 MeV)



- low-power (<5 kW), low duty cycle (0.1%) PSB injector
- under construction and designed for high duty cycle (HP-SPL),
- tunnel can be extended in a straight line for the SPL,
- radiation protection and civil engineering works foresee high-duty cycle operation (up to 10%),
- start of operation foreseen for 2013,

SPL construction, stage 2:

LP-SPL (4 GeV)

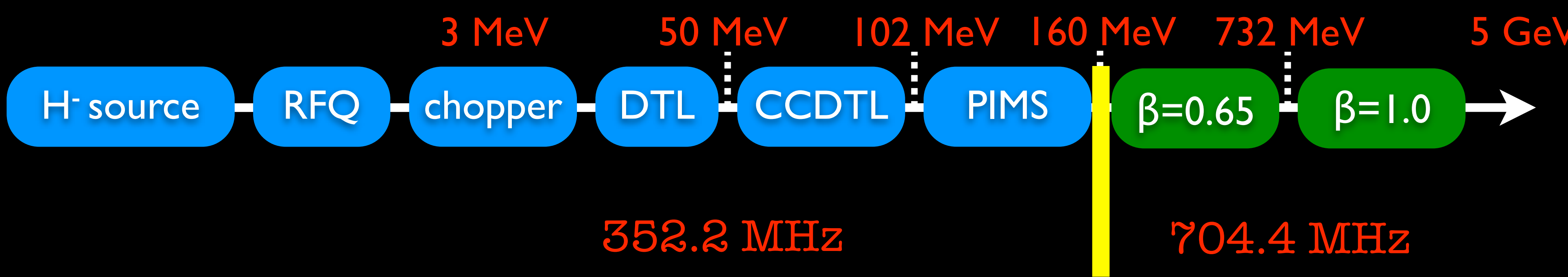


- construction of Low-Power SPL together with PS2,
- main users: PS2 (LHC), ISOLDE upgrade, EURISOL-0 (?),
- earliest operation in 2018

kinetic energy	4 GeV
beam power (@ 4 GeV)	0.19 MW
repetition rate	~2 Hz
pulse length	1.2 ms
average pulse current	20 mA
protons p. pulse	$1.5\ 10^{14}$
length (SC linac)	400 m

SPL construction, stage 3:

HP-SPL (5 GeV)

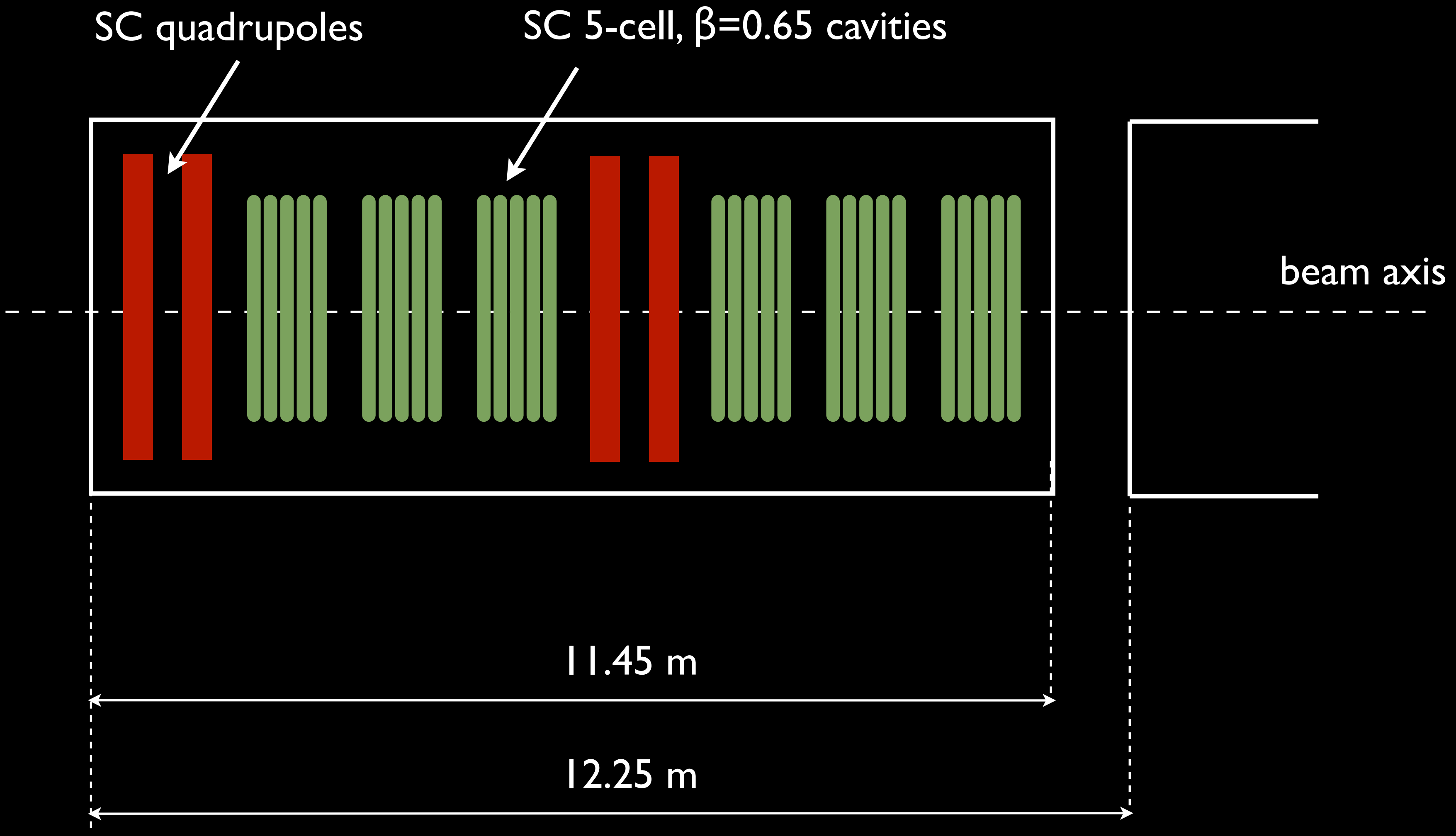


- addition of klystrons,
- cavities from 4 to 5 GeV,
- replacement of all modulators,
- upgrade of electric/cryogenic infrastructure,
- possible high-power users: EURISOL, neutrinos, LHeC,
- possible start of operation: 2020

kinetic energy	5 GeV
beam power	3-8 MW
repetition rate	50 Hz
pulse length	up to1.2 ms
average pulse current	0-40 mA
protons p. pulse	1.5 (3) x 10^{14}
length (SC linac)	472 m

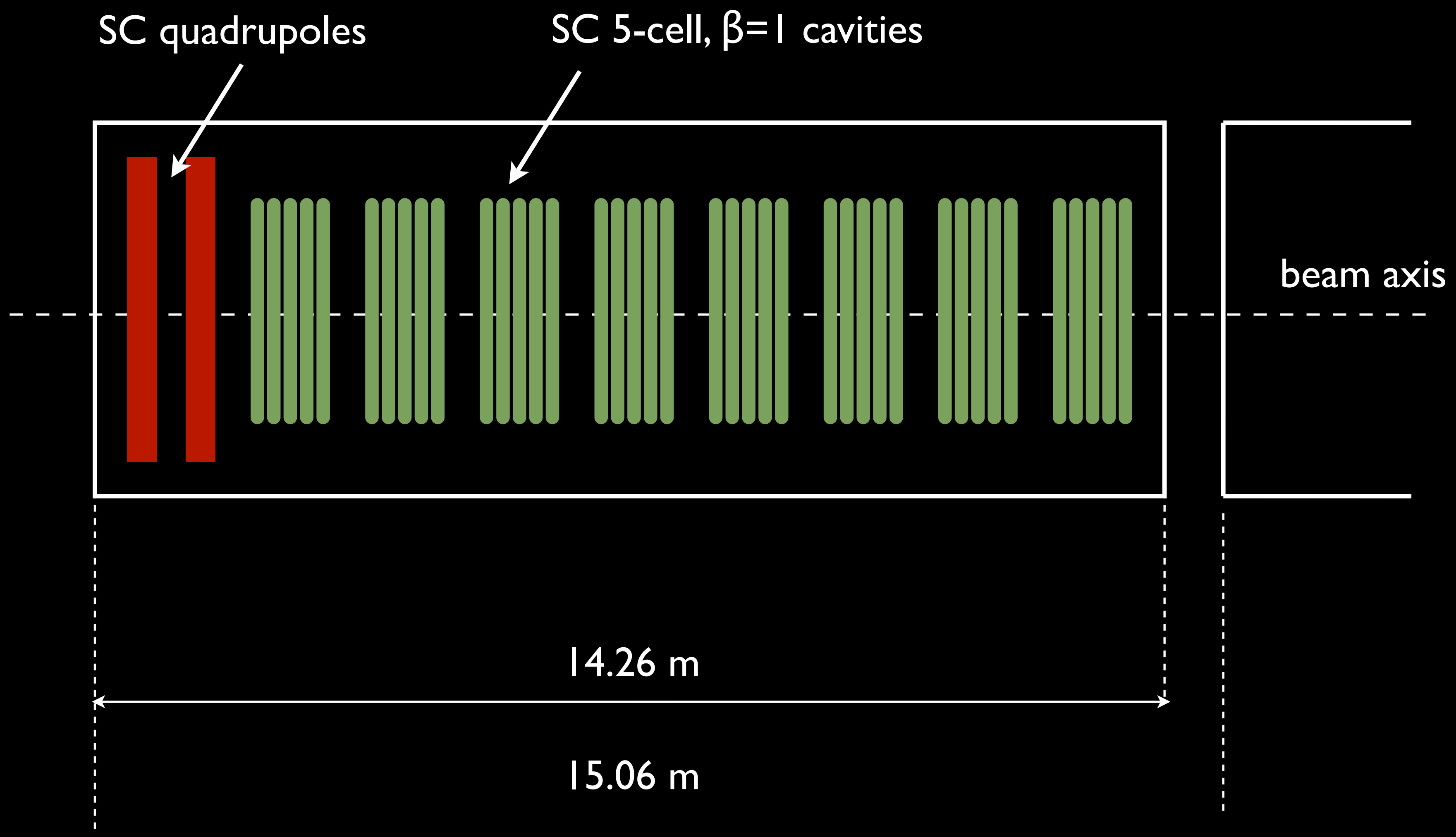
low-beta cryo-module

doublet focusing, 6 cavities (704 MHz) per cryo-module



high-beta cryo-module

doublet focusing, 8 cavities (704 MHz) per cryo-module



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SPL parameters

operation type	low-power	high-power low-current	high-power high-current
E [GeV]	4	2.5 (**or** 5)	2.5 (**and** 5)
P_{beam} [MW]	0.192	3 (6)	4 (+4)
f_{rep} [Hz]	2	50	50
$I_{average}$ [mA]	0-20	0-20	0-40
t_{pulse} [ms]	≤1.2	≤1.2	≤0.8 (+0.4)
$n_{protons/pulse}$ [10^{14}]	≤1.5	≤1.5	≤2 (+1)
main user	PS2/ISOLDE	PS2/neutrinos/ EURISOL	PS2/neutrinos/ EURISOL

+ LHeC (tbd)

each option has impact on the civil engineering and technical choices for the LP-SPL!

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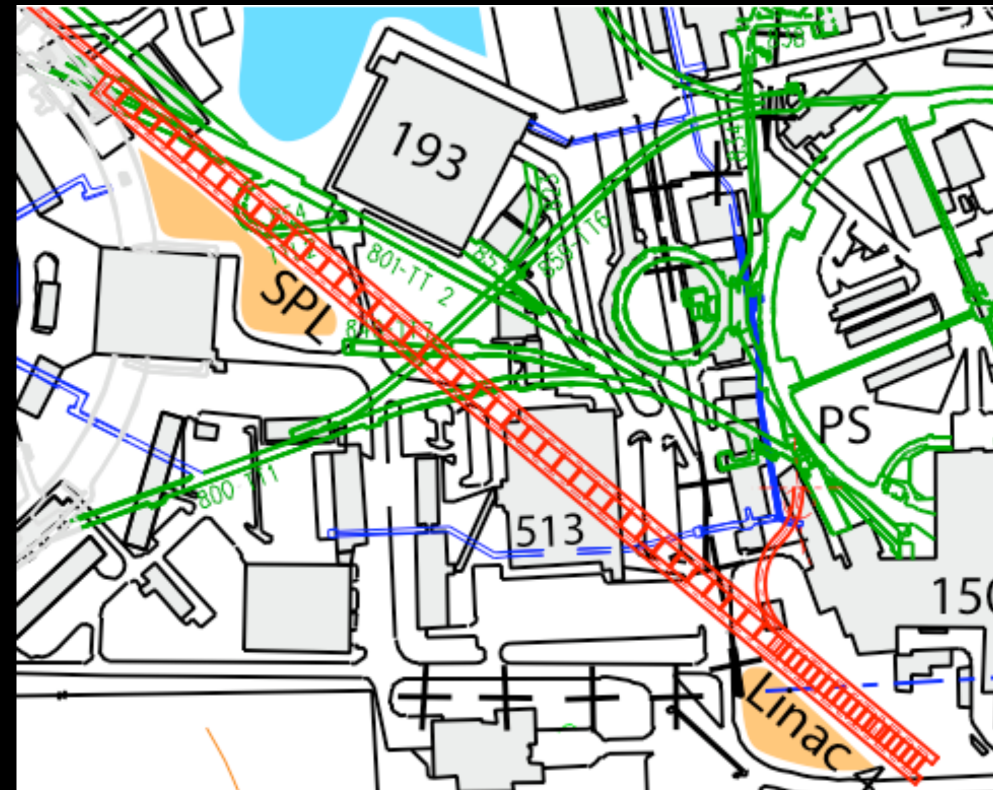
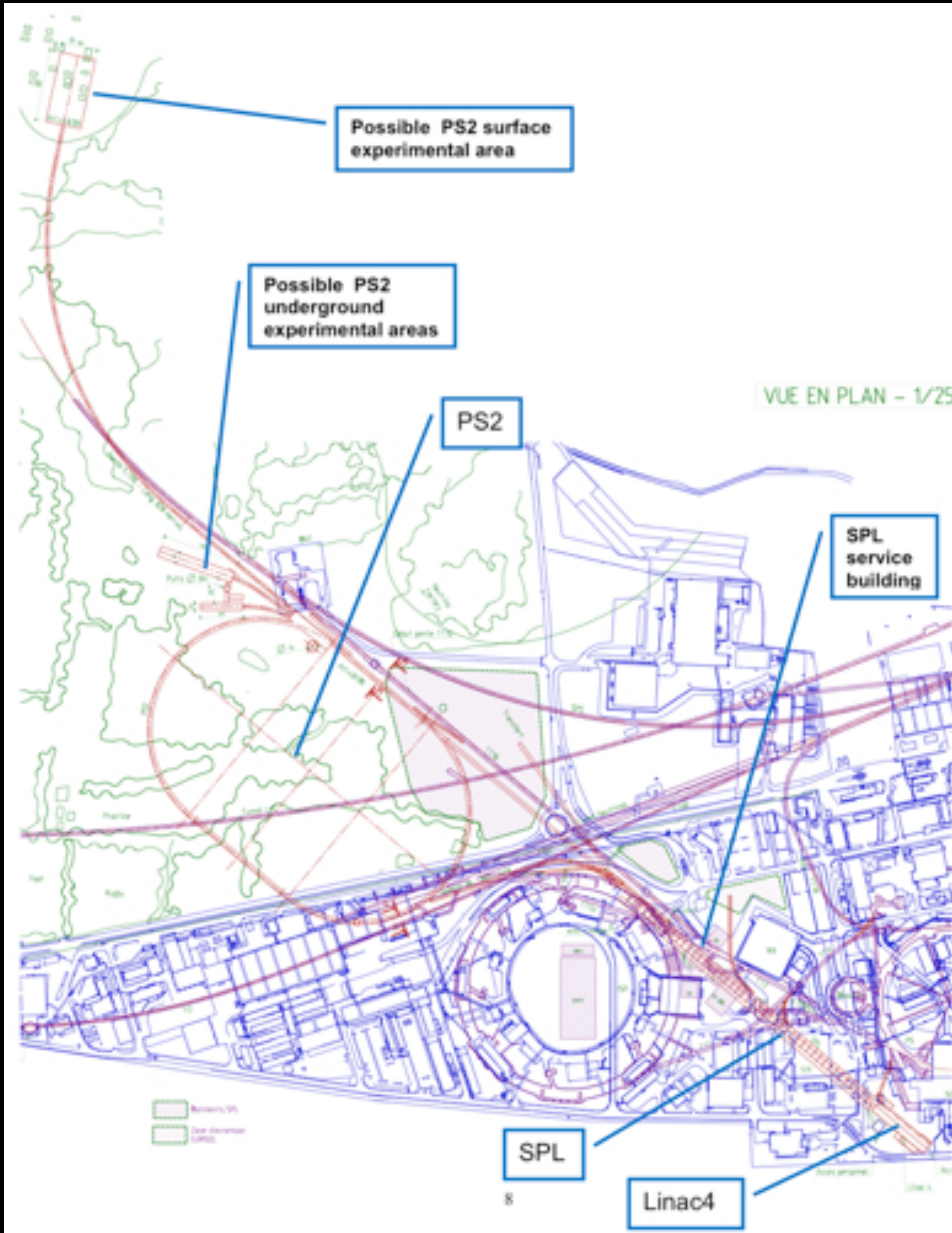
Site decision



CERN-AB-2007-061 PAF

layout on the CERN site together with Linac4/PS2

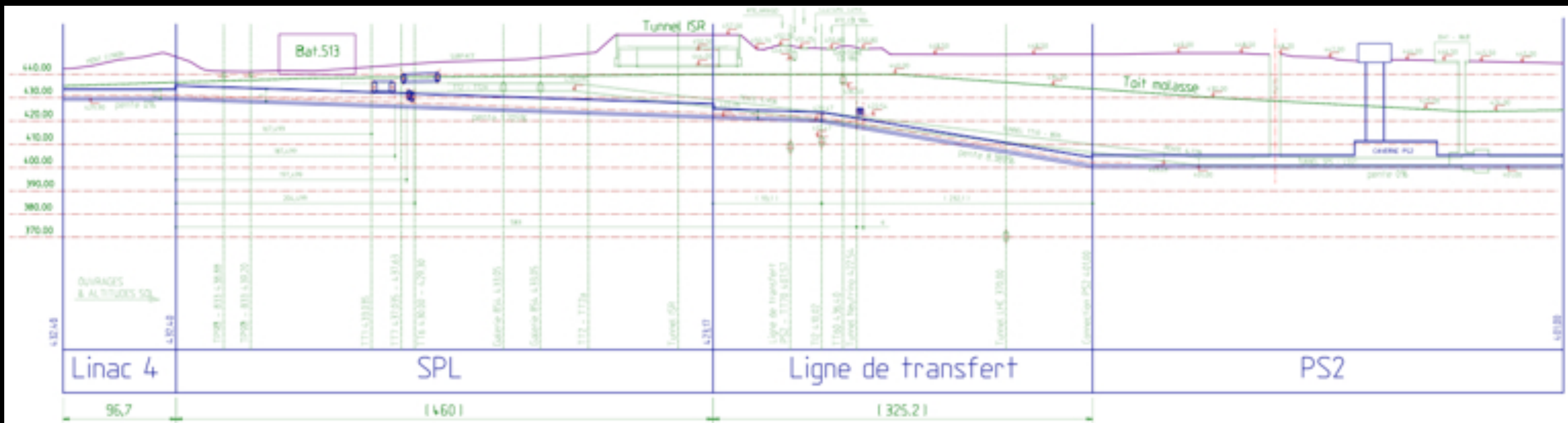
site layout: Linac4/SPL/PS2



The Linac4 team was encouraged by the CERN management to make the Linac4 location consistent with a full proton injector upgrade.

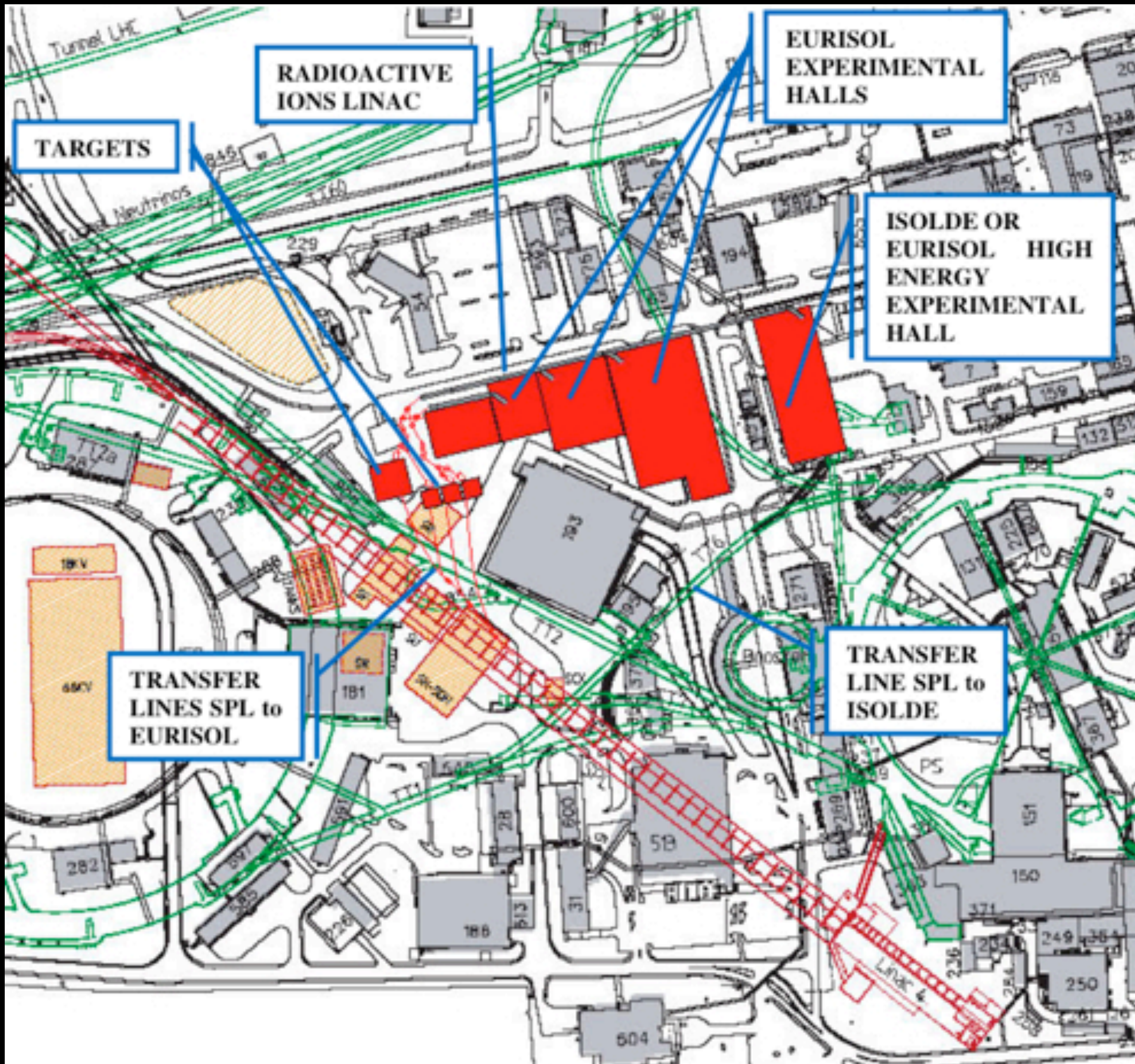
- Linac4 is in a position, that allows the construction of all new LHC injectors,
- including surface buildings,
- and possible experimental areas for the PS2 beam

site layout: tunnels



- The SPL tunnel trajectory keeps necessary distances from existing tunnels/buildings (computing building 513, nTOF, transfer lines...)

site layout: EURISOL



- SPL is compatible with a possible location for EURISOL on the CERN site,
- (very preliminary layout!!)

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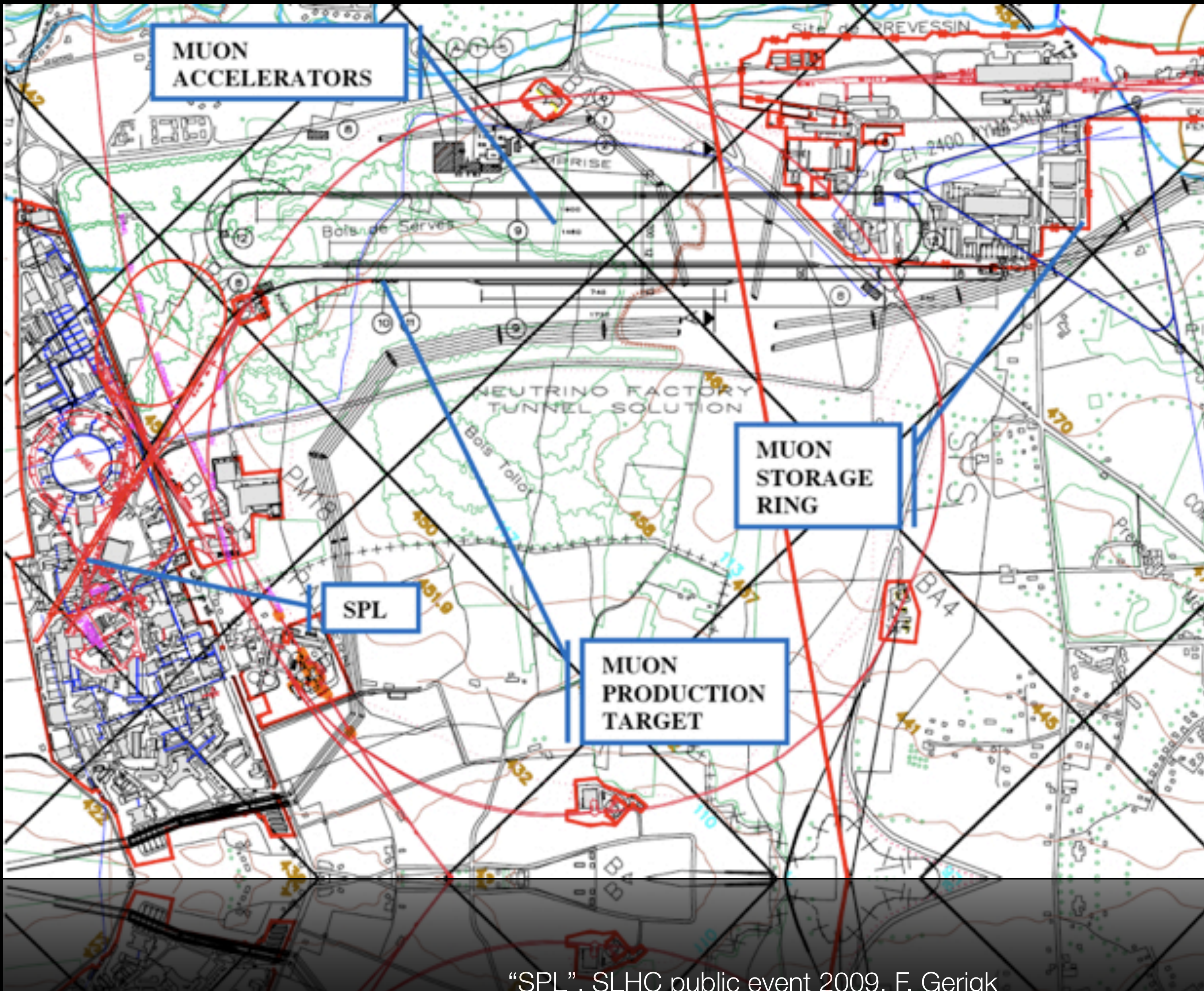
site layout: neutrinos



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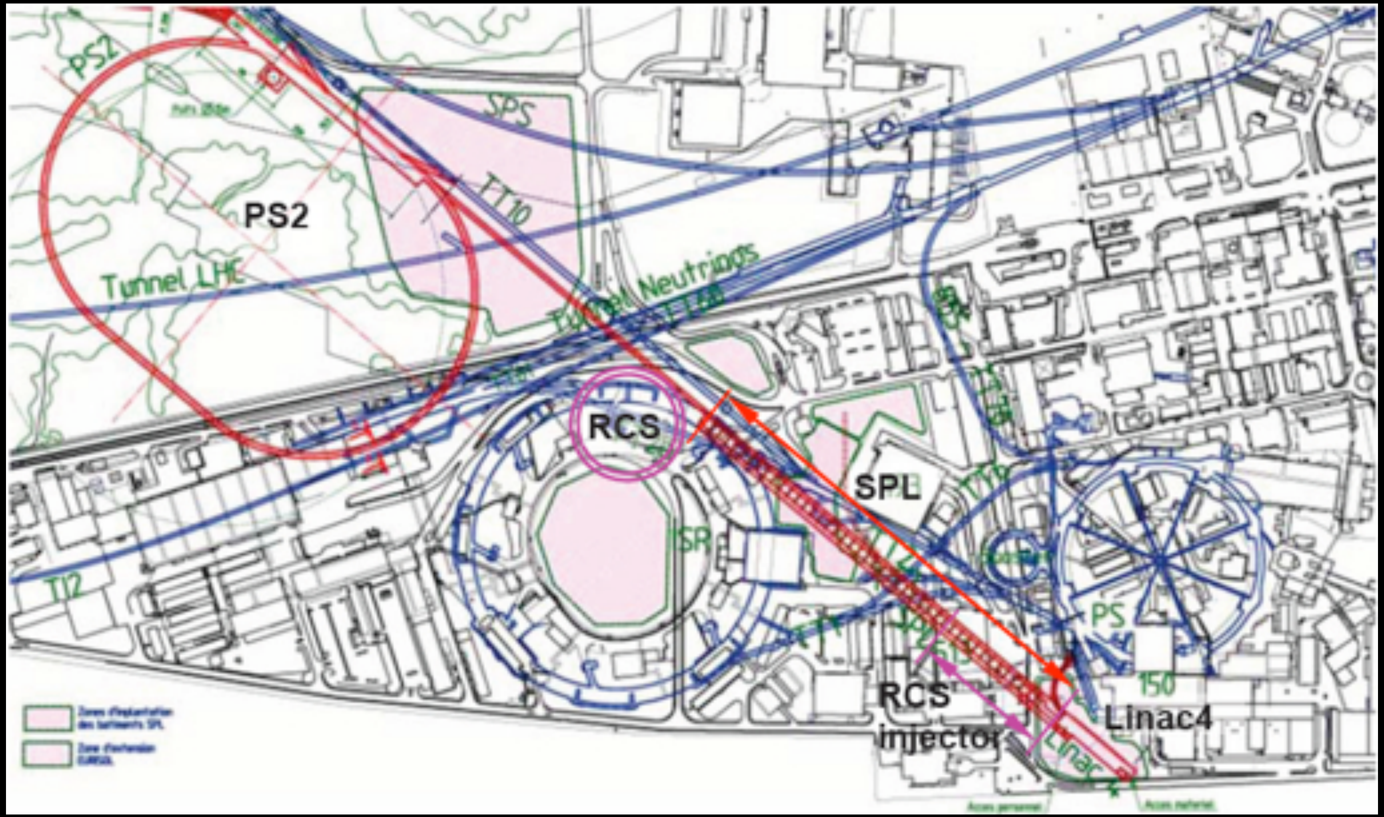

LP-SPL vs RCS

CERN-AB-2007-014-PAF

RF frequency & cryogenic temperature

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LP-SPL vs RCS

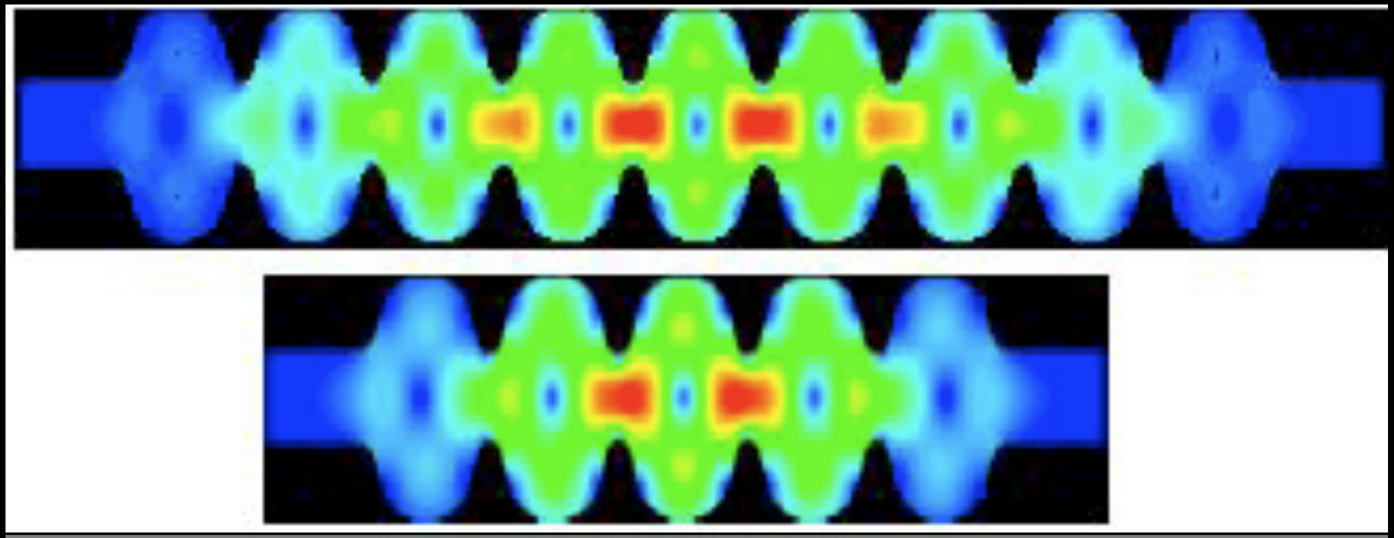
Why not using a small RCS + “small” injector linac instead of the SPL?

Because at moderate cost (+ 30%) the LP-SPL carries the potential for high-power proton physics!

Furthermore we find the following relative merits:

	Filling time PS2	Time structure for LHC	relative proton rate	Fixed target physics	Ions	upgrade potential	relative cost*
SPL	0.6 ms	inherent	2.5	ideal	acceptable	high	1.28
RCS	1.3 s	different	1	acceptable	ideal	low	1
Advantage	SPL	SPL	SPL	SPL	RCS	SPL	RCS

* only items that differ between both options have been costed



Parameter review

CERN-AB-2008-067

RF frequency & cryogenic temperature

RF frequency review: 704 MHz

frequency	704 MHz	1408 MHz
length	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
long. 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

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cryogenic temperature review: 2K

@ 704 MHz	T [K]	eq. capacity @ 4.5 K [kW]	el. 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!

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summary of the review

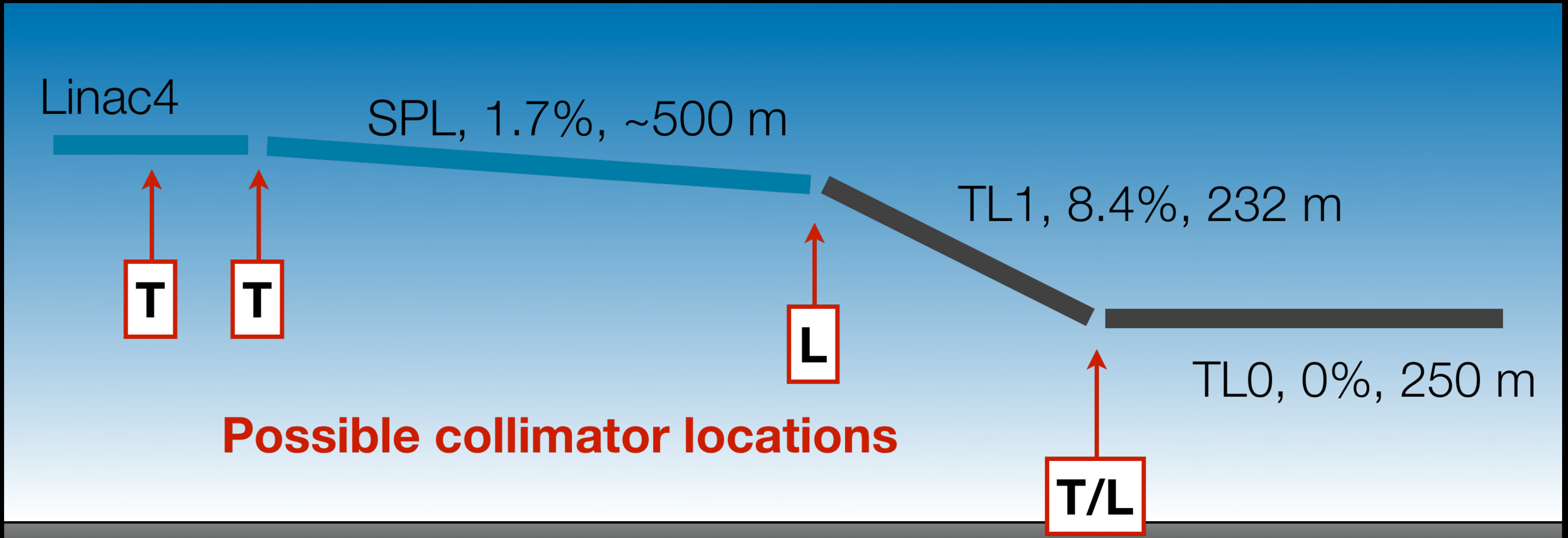
frequency/temperature:

- the original choices of 704 MHz and 2 K were confirmed,

cavity gradient:

- 25 MV/m "on average" are very challenging and may have a high cost (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!!



SPL collaborations

1st meeting, 11-12 Dec 2008

sLHC project note in preparation

agreed collaborations:

institute	subject
CEA Saclay (France)	▪ Design and construction of 2 **β=1 cavities** (EUCARD task 10.2.2), ▪ Helium vessels for 2 cavities & tools for cryomodule assembly (French in-kind contribution), ▪ Test of existing β=0.5 cavity in pulsed mode and participation to LLRF design (CNI sLHC)
CNRS/IPN Orsay (France)	▪ Design and construction of **β=0.65 cavity** (EUCARD task 10.2.1), ▪ Design and construction of prototype cryomodule (French in-kind contribution)
Soltan Institute (Poland)	▪ FLUKA simulations for **radiation protection** issues, ▪ **collimator** development,
ESS-S (Scandinavia)	▪ **beam dynamics,** ▪ **RF** developments,
Cockroft Institute (UK)	▪ participation to specification & design of **RF system**, ▪ study of RF components (RF power distribution, vector modulators, phase-locked magnetrons), ▪ study & design of low-power **collimation** systems,

.. under negotiation

institute	subject
ESS-Bilbao (Spain)	Design and construction of **50 Hz klystron modulator**,
ESS-Debrecen (Hungary)	..to be defined
Rostock University (Germany)	**HOM damper** design & analysis,
Stony-Brook/BNL (USA)	Design and construction of prototype **β=1 cavity(ies), HOM damping**
TEMF Darmstadt (Germany)	**Beam** influence of **RF** power coupler,
TRIUMF (CANADA)	Design and construction of prototype **β=0.65 cavity(ies), HOM damper specifications**

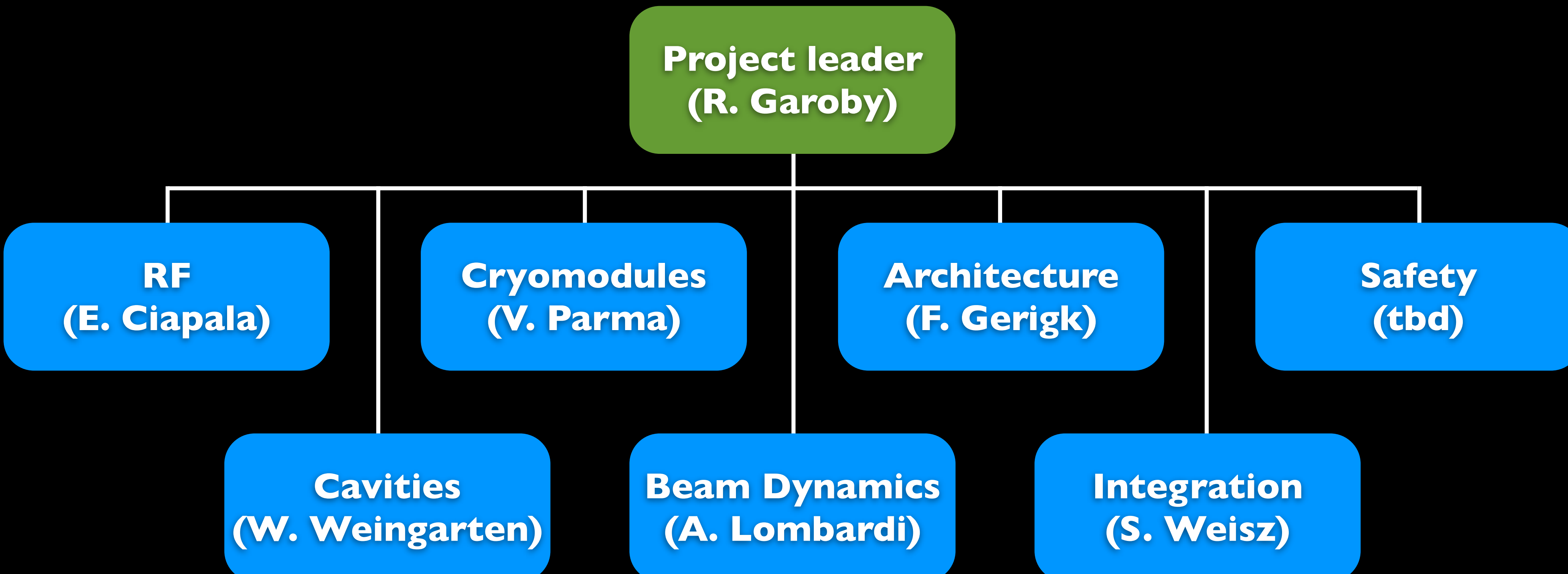
untreated subjects:

need	recommended action	recommended main contributor
High-power RF test stand for complete cryo-modules	upgrade SM18 at CERN	■ CERN (infrastructure) ■ ESS-Bilbao (modulator)
cost comparison of RF distribution systems	study, system definition, discussion	■ CERN (study) ■ all partners (discussion)
test series of cavities (12 x β=1, 2-4 x β=0.65), test of full cryo-module	■ build and test more cavities, ■ establish realistic gradient,	■ Stony Brook/BNL/AES: β=1, ■ TRIUMF: β=0.65, ■ CERN: β=1
adapt CEA design for RF coupler/tuner to SPL	■ study, build, test devices, ■ integration in cryo-module	?
HOM dampers	■ study, build, test devices, ■ integration in cryo-module	?
define longitudinal layout (lattice, instrumentation, beam extraction)	Design	■ CERN

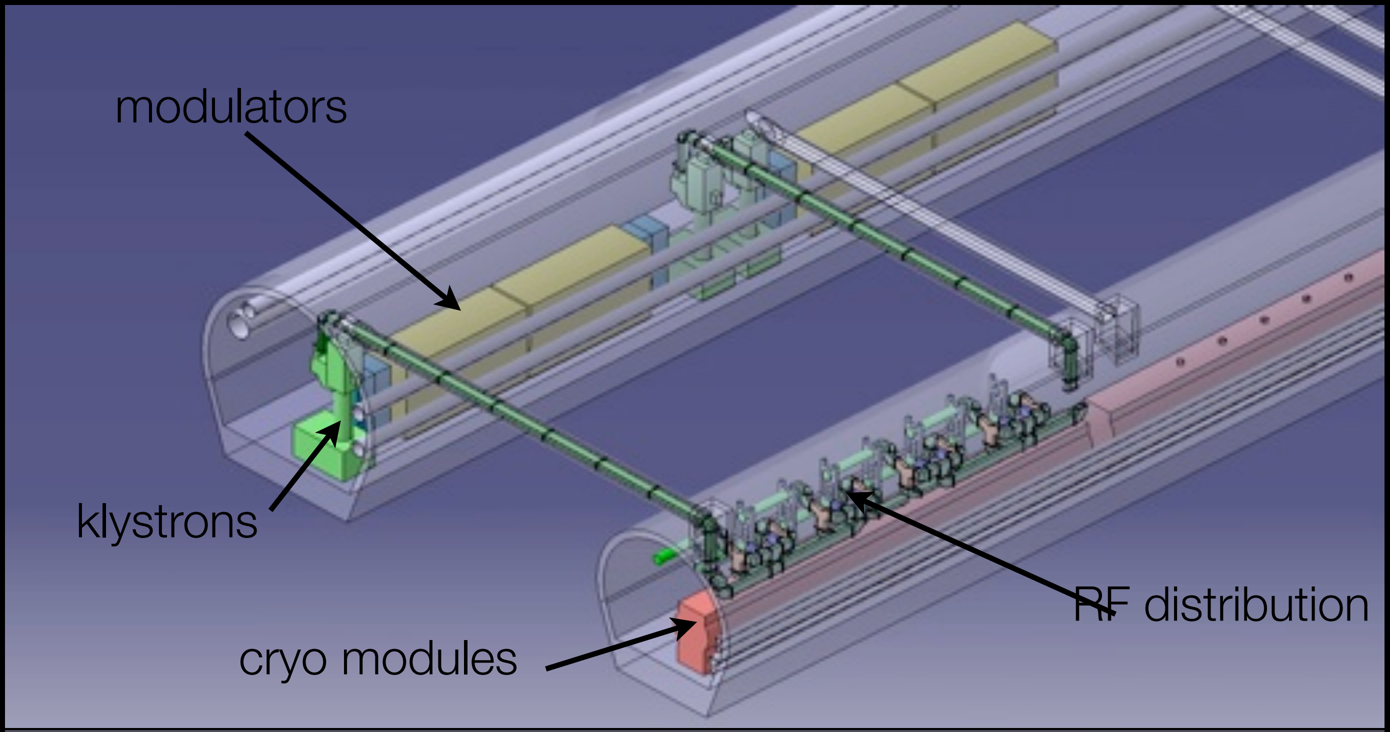
organisation of collaboration

- Four working groups were created:
  - ➡ beam dynamics/loss management,
  - ➡ high-power RF equipment: power distribution, circulators, loads, vector modulators,
  - ➡ cryo-module and integration,
  - ➡ cavity design & construction: cavity geometry, HOM damper, power coupler & manufacturers, processing, testing
- working groups have common meetings, phone/video conferences,
- collaboration meetings with lab representatives 1-2x per year,
- one yearly meeting at CERN open to everyone,
- a collaboration “constitution” in form of an MoU will be circulated and signed by all collaborators,

general SPL organisation at CERN



core team meets once a week



overall planning

is mainly determined by civil engineering

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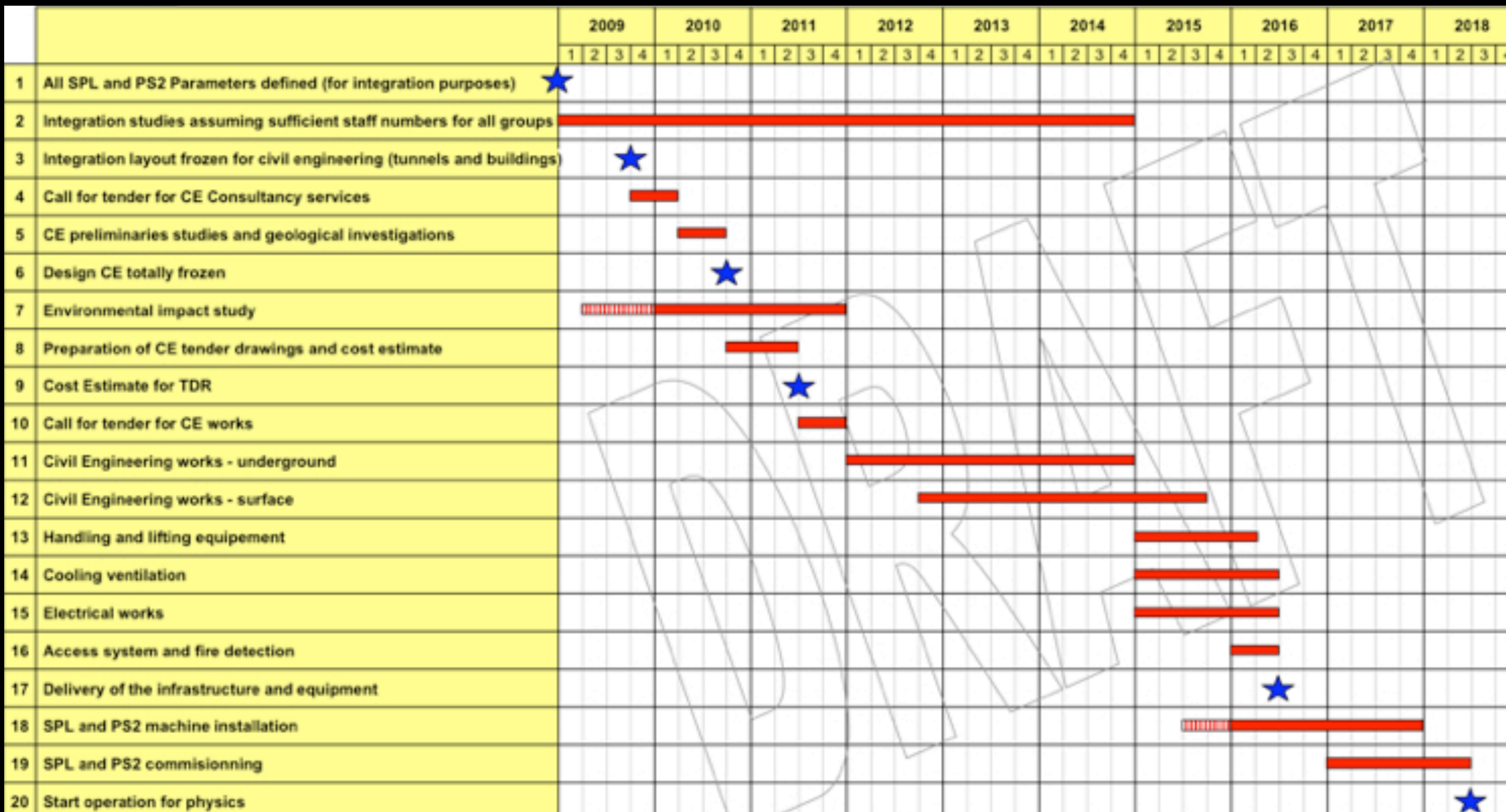
(agressive) civil engineering **draft** planning



time is running!

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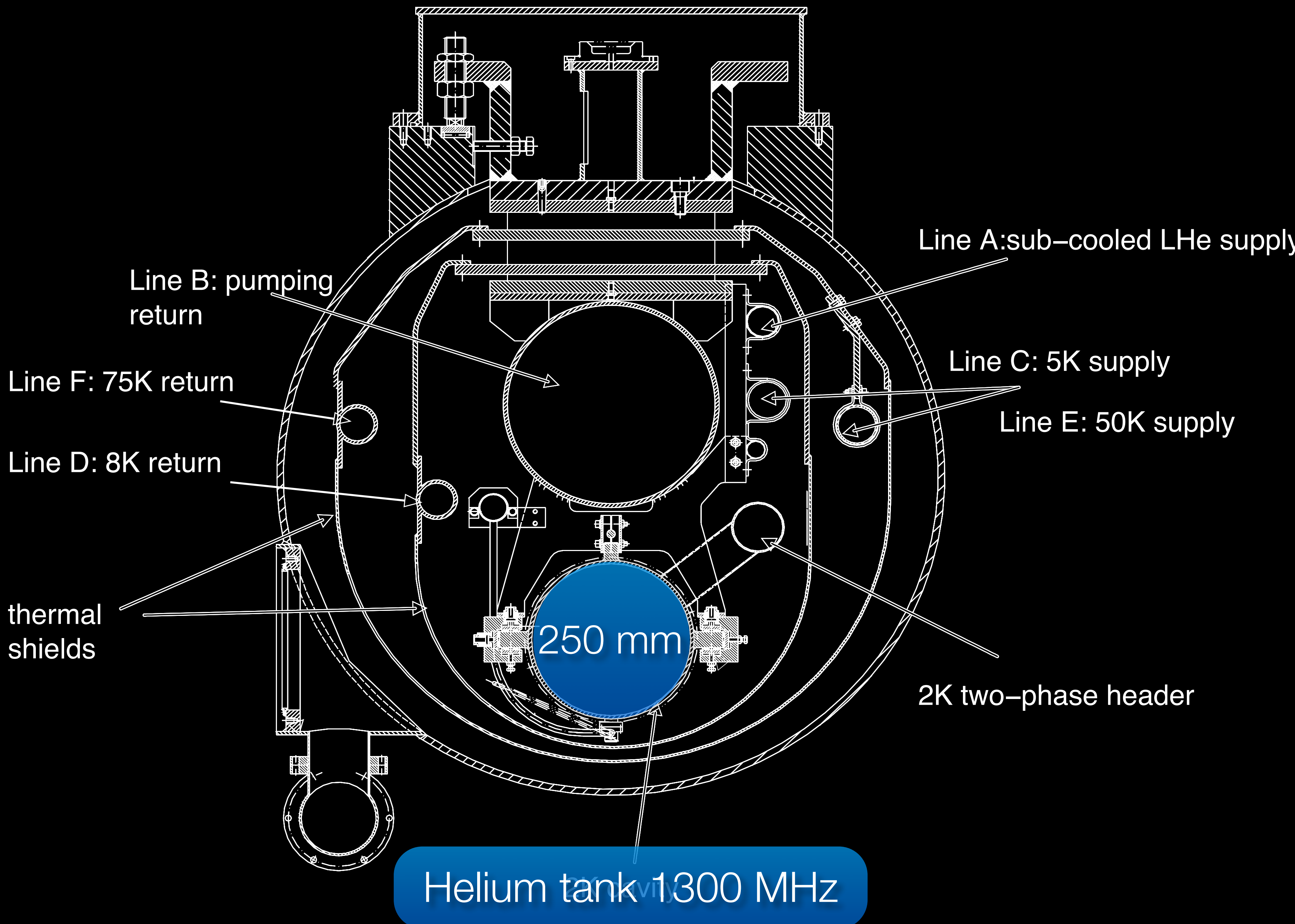
summary:

- the SPL is consistent with the general proton injector upgrade plan,
- the (old) CERN management endorsed the LP-SPL over an RCS based solution,
- a site layout for all new injectors was elaborated,
- a technical baseline exists (and was confirmed by a review) but needs to be verified by actual hardware tests,
- The “SPL collaboration” is taking shape,
- technical design report foreseen for 2011, earliest start of construction in 2012,
- the current planning can only succeed with sufficient resources!

additional slides

size of Helium tank



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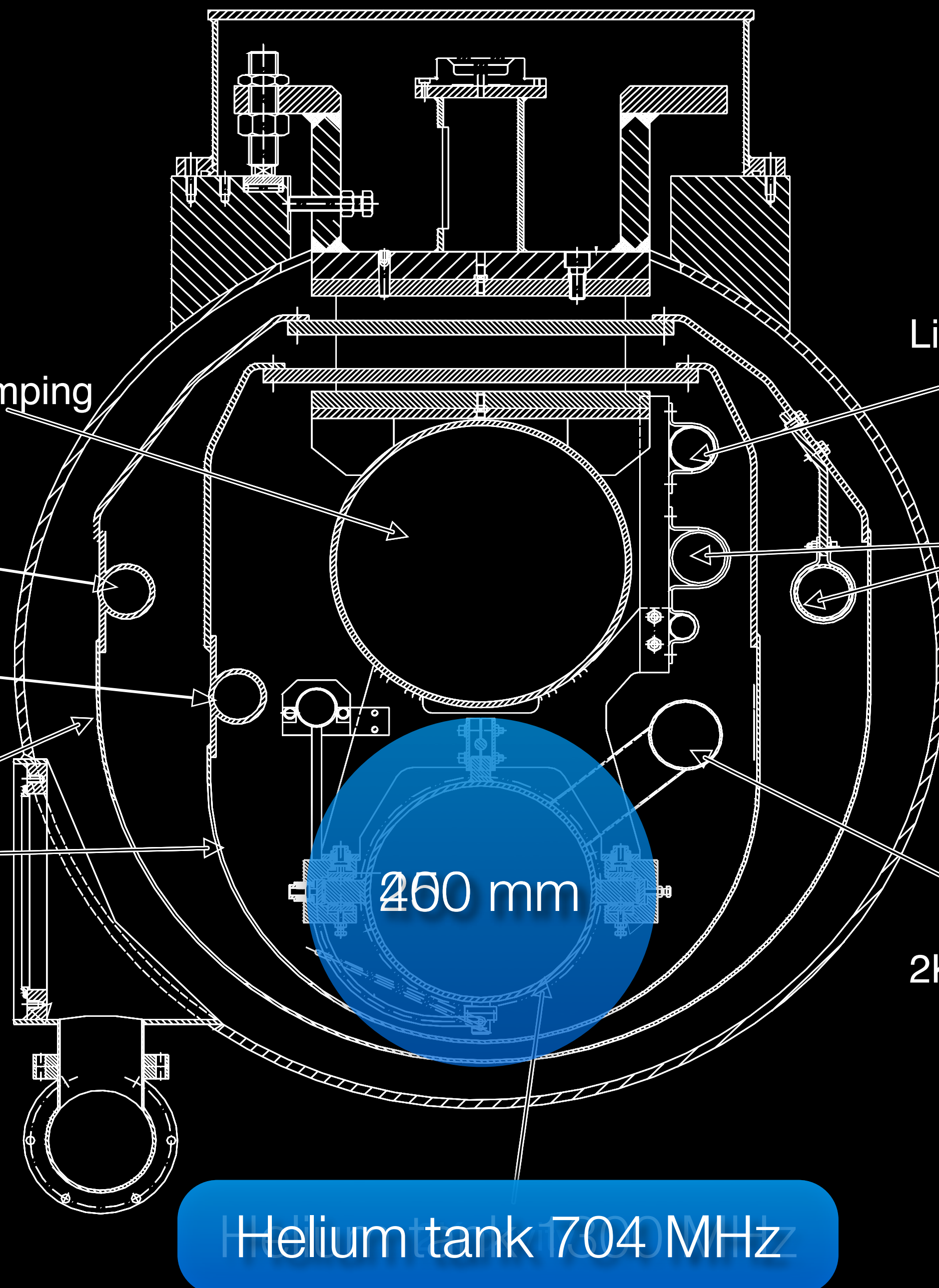
size of Helium tank



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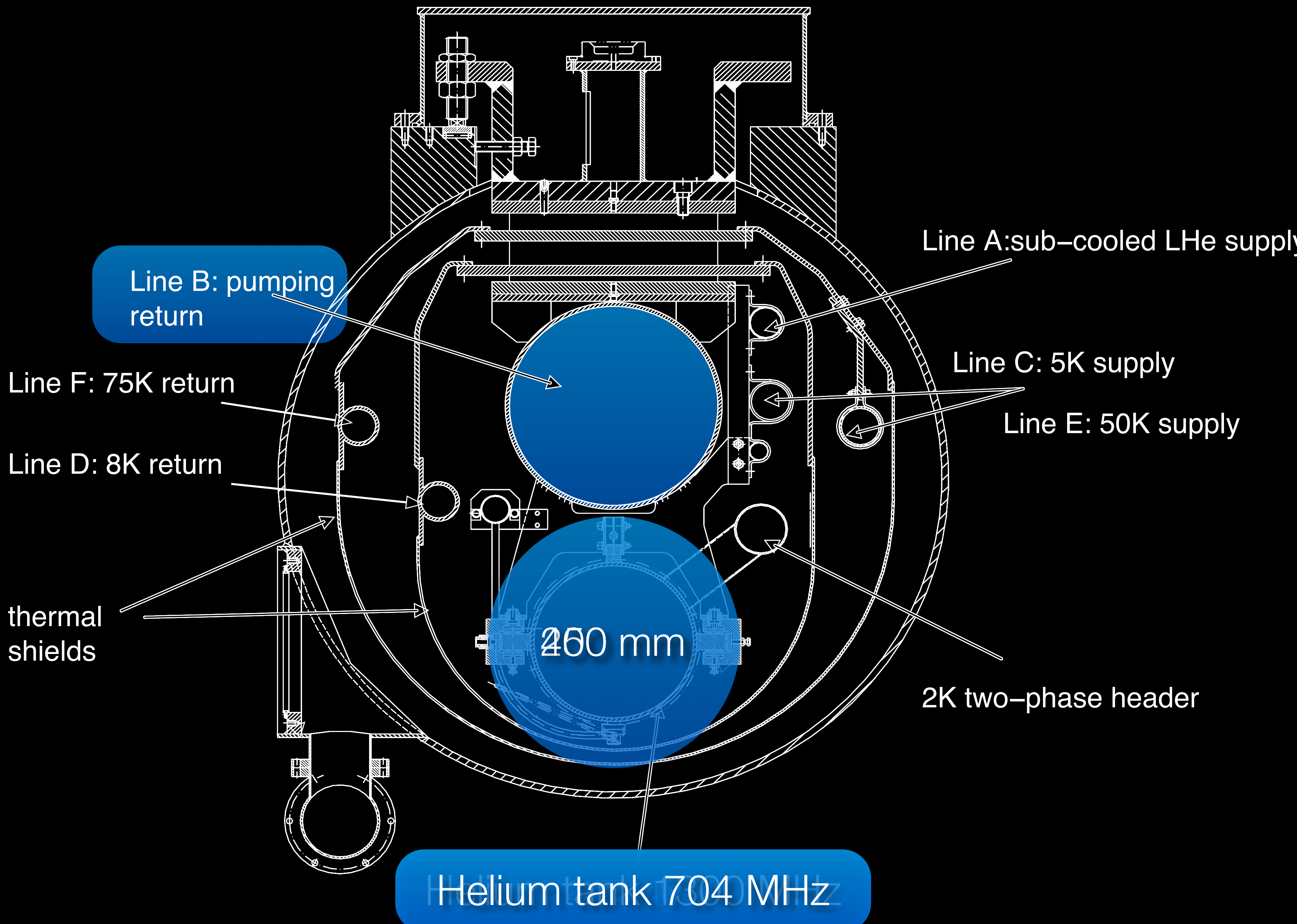
size of Helium tank



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Can we re-use the ILC cryo-module?

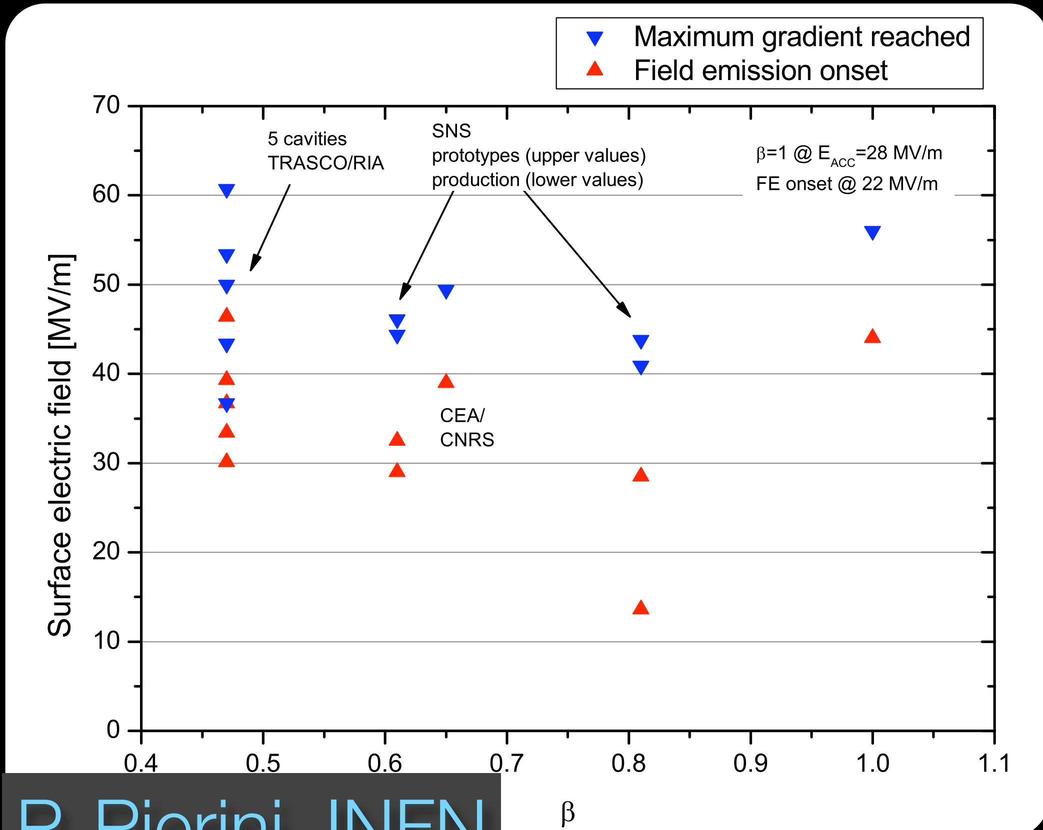
At 2K we can re-use the ILC design principle for both frequencies, but:

- the port openings will have to be adapted to the SPL cavities (power coupler, HOM coupler, ...),
- the design has to be adopted for the SPL slope of 1.7 deg,
- dynamic heat load of the HPSPL is estimated to be ~10 times higher than for ILC,

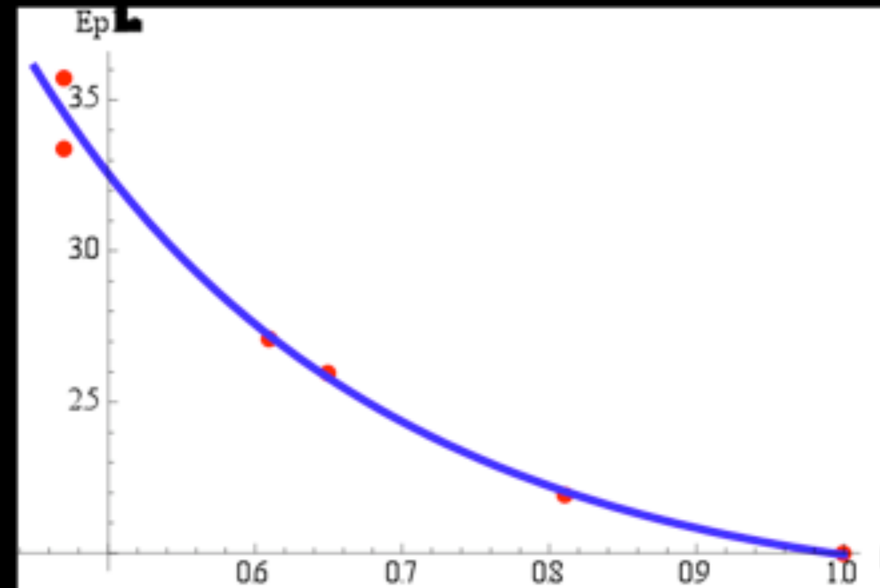
➡ an identical copy of the ILC cryo-module cannot be used!

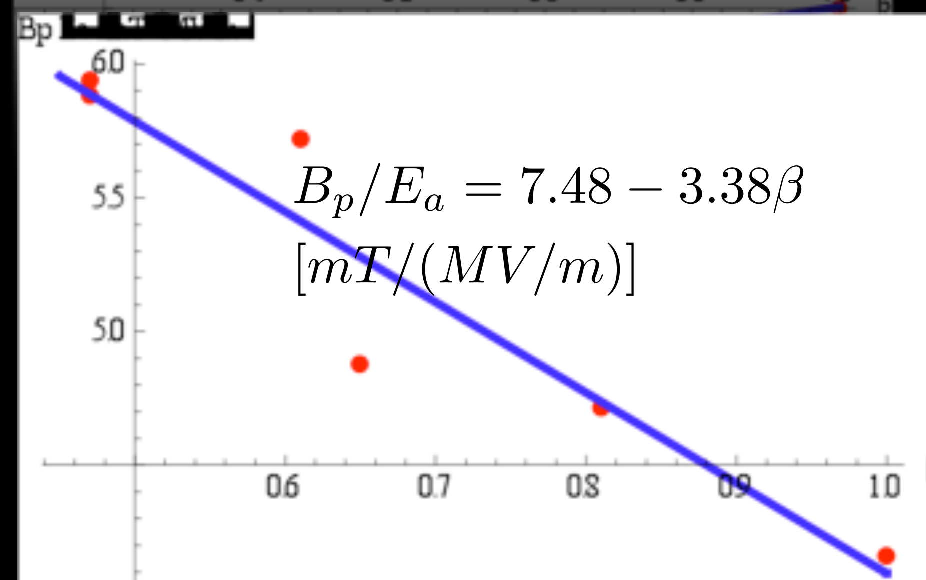
➡ unlikely that we can have a major saving on the cryo-module cost, when going to 1408 MHz!

SC cavity performance for β<1



P. Pierini, INFN





gradient independent of freq.

25 MV/m looks challenging but not impossible!

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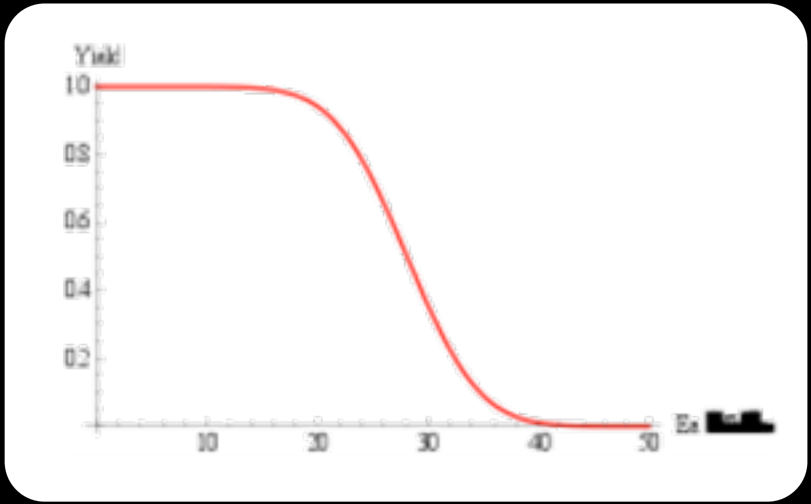
yield vs performance



for electropolished ILC cavities at 1300 MHz:

- at 28.1 MV/m the yield is ≈ 50%,
- at 25 MV/m the yield is ≈ 75%,

but basically no difference between single cell and multi-cell results!

Laboratory	freq. [MHz]	<E_{acc}> [MV/m]	ΔE_{acc} [MV/m]	ΔE_{acc}/ E_{acc} [%]	E_{acc} at 90/50% yield
DESY, 9-cell	1300	28	5.2	19	22/28
ORNL/JLAB, 6-cell β=0.61, (extrapolated to β=1)	805	17.1 (23)	1.9 (2.6)	11 (11)	15/17 (20/23)
ORNL/JLAB, 6-cell β=0.81, (extrapolated to β=1)	805	18.2 (20)	2.6 (2.8)	14 (14)	15/18 (16/20)

Q dependance at 25 MV/m

at 2K: $Q_{704\ MHz} = 2.5 \times Q_{1408\ MHz}$

at 4.5K: $Q_{704\ MHz} = 3.0 \times Q_{1408\ MHz}$

at 704 MHz: $Q_{2\ K} = 21 \times Q_{4.5\ K}$

at 1408 MHz: $Q_{2\ K} = 26 \times Q_{4.5\ K}$

beam dynamics: longitudinal errors

Case I: ΔE (1σ)= 125 keV/±0.5 deg from Linac4, ±0.5%/±0.5 deg in SPL. **Case II:** ΔE (1σ)= 125 keV/±1 deg from Linac4 ±1%/±1deg in SPL.

SPL type	nominal improved		high frequency		spoke/elliptical	
	case I	case II	case I	case II	case I	case II
frequency [MHz]	704.4		1408.8		352.2/1408.8	
beta families	0.65/0.92		0.6/0.76/0.94		0.67/0.8/0.94	
$\Delta\varepsilon_{x,rms}$ [%]	0.07±0.27	0.21±0.41	0.24±0.62	1.02±1.11	0.05±0.22	0.24±0.49
$\Delta\varepsilon_{y,rms}$ [%]	0.18±0.26	0.59±0.53	0.10±0.38	0.42±0.75	0.09±0.24	0.33±0.50
$\Delta\varepsilon_{z,rms}$ [%]	0.40±0.58	1.13±1.33	0.27±0.70	1.90±1.88	0.19±0.36	0.81±0.76
ΔE [MeV]	±2.0	±3.8	±1.8	±3.5	±1.8	±3.5
Δφ [deg, st.dev.]	0.26	0.57	0.30	0.61	0.30	0.61
Lossy runs	0	0	9/500	21/500	0	0

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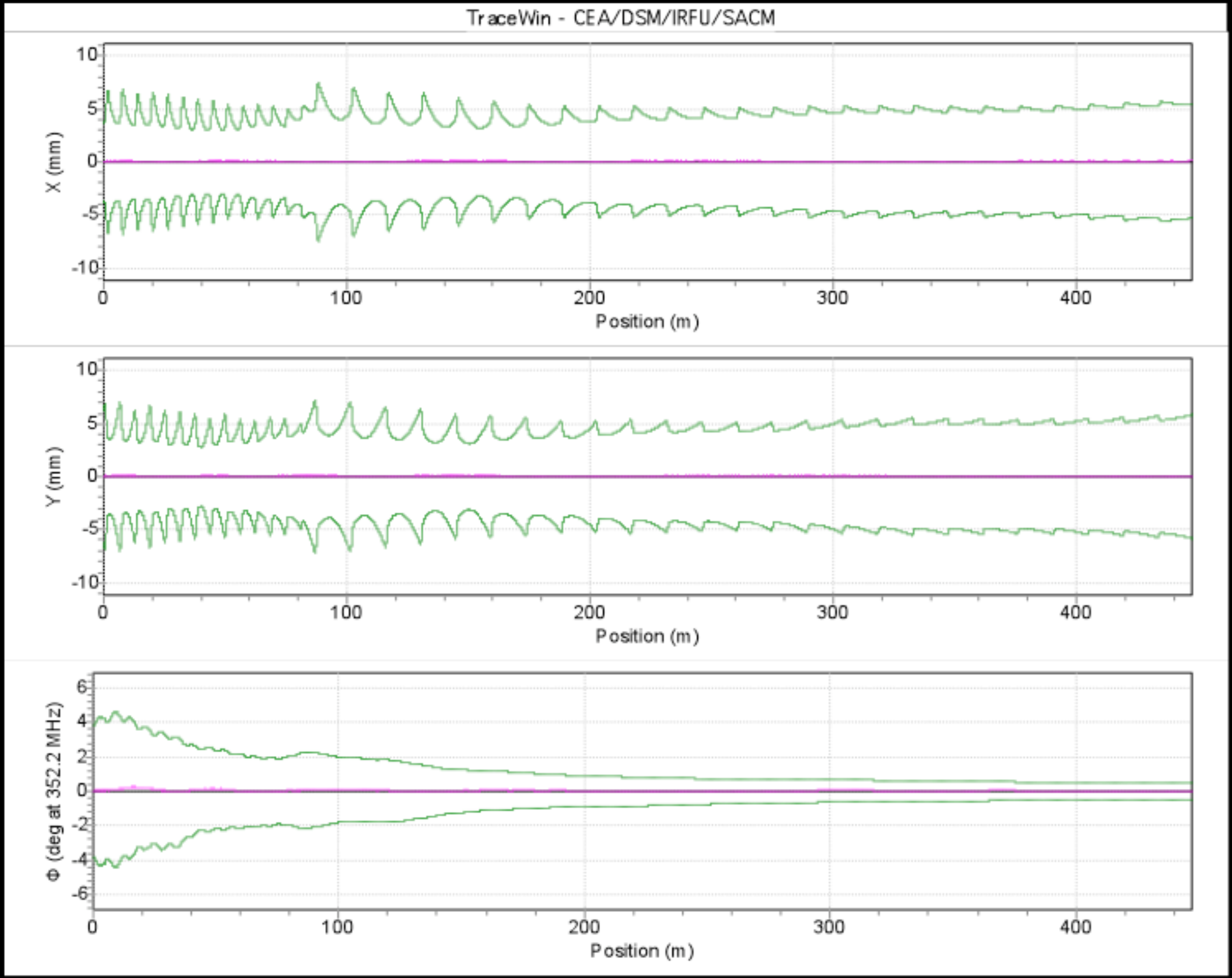
beam dynamics: 5 x rms envelopes

nominal:



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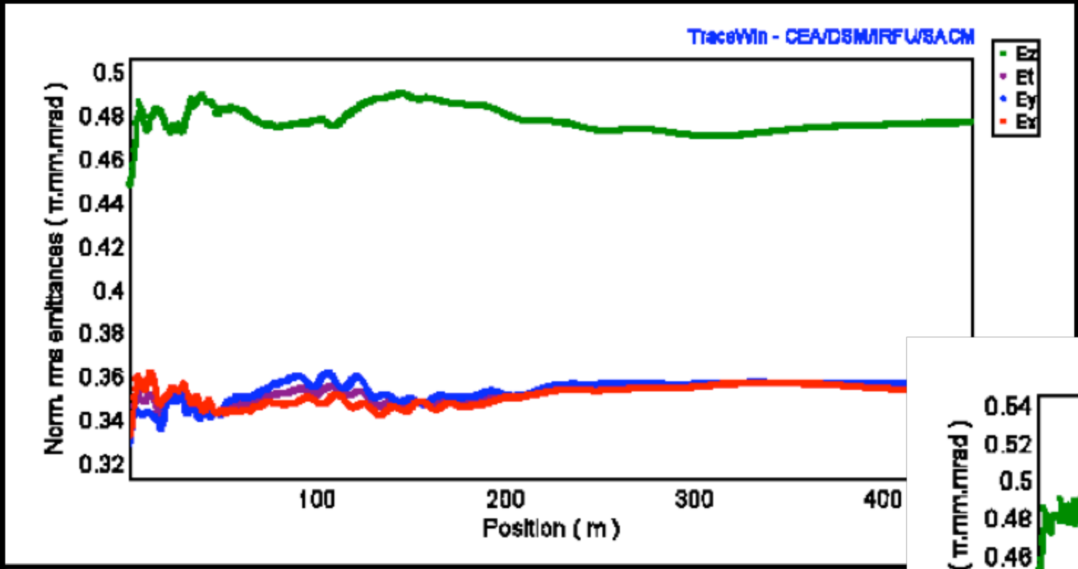
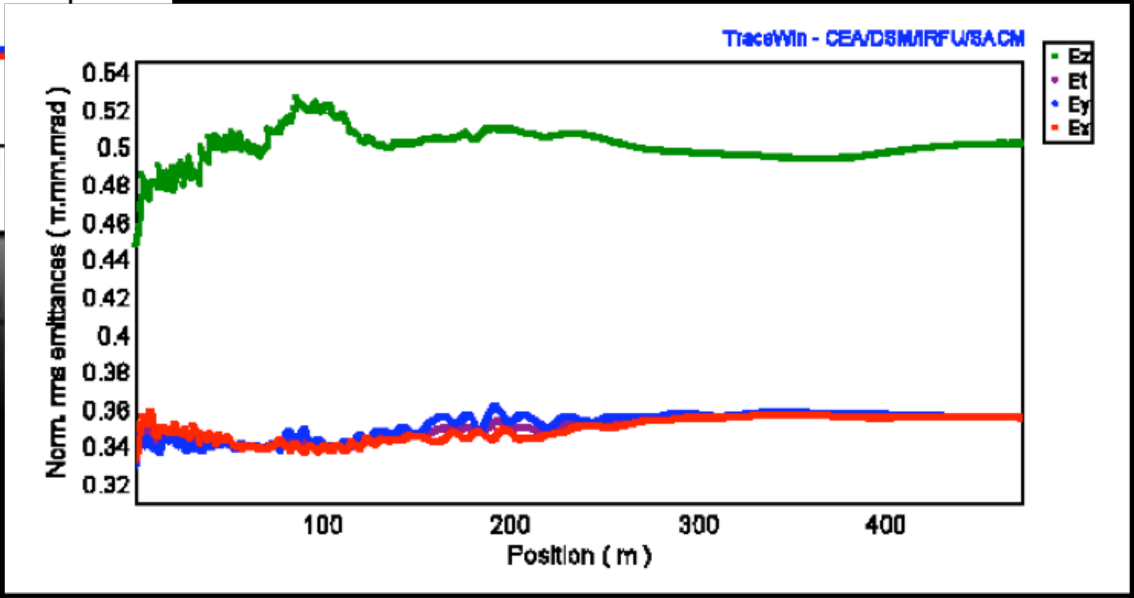
rms emittances



704 MHz nominal

1408 MHz elliptic cavities



longitudinal plane is more sensitive for 1408 MHz due to 4x frequency jump