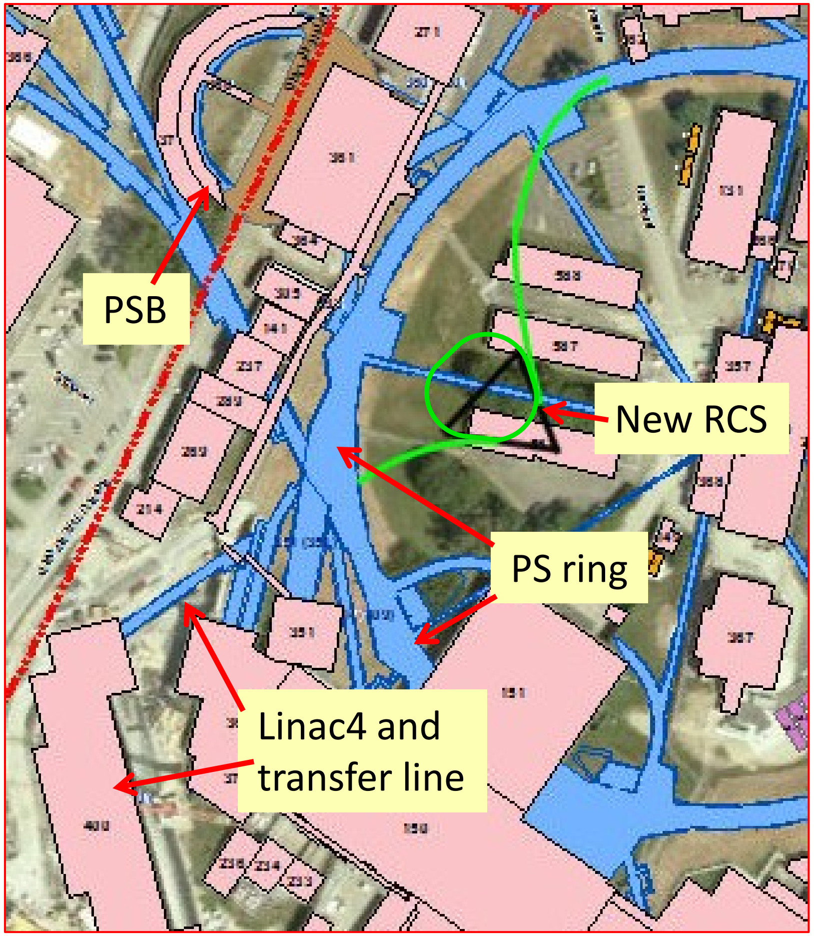
Plans for the PS Injector

K. Hanke
for the LIU-PSB team and RCS task force

Plans for the upgrade of the PS injector are presented. The baseline scenario consists in a consolidation and upgrade of the existing PS Booster. The PSB upgrade can be broken up in the upgrade of the injection (H- injection from Linac4) and a possible energy upgrade of the machine from 1.4 to 2.0 GeV. As an alternative, a feasibility study for the replacement of the Booster by a Rapid Cycling Synchrotron (RCS) has recently started. Both scenarios are presented along with time lines and resource requests, notably for the first long LHC shutdown.

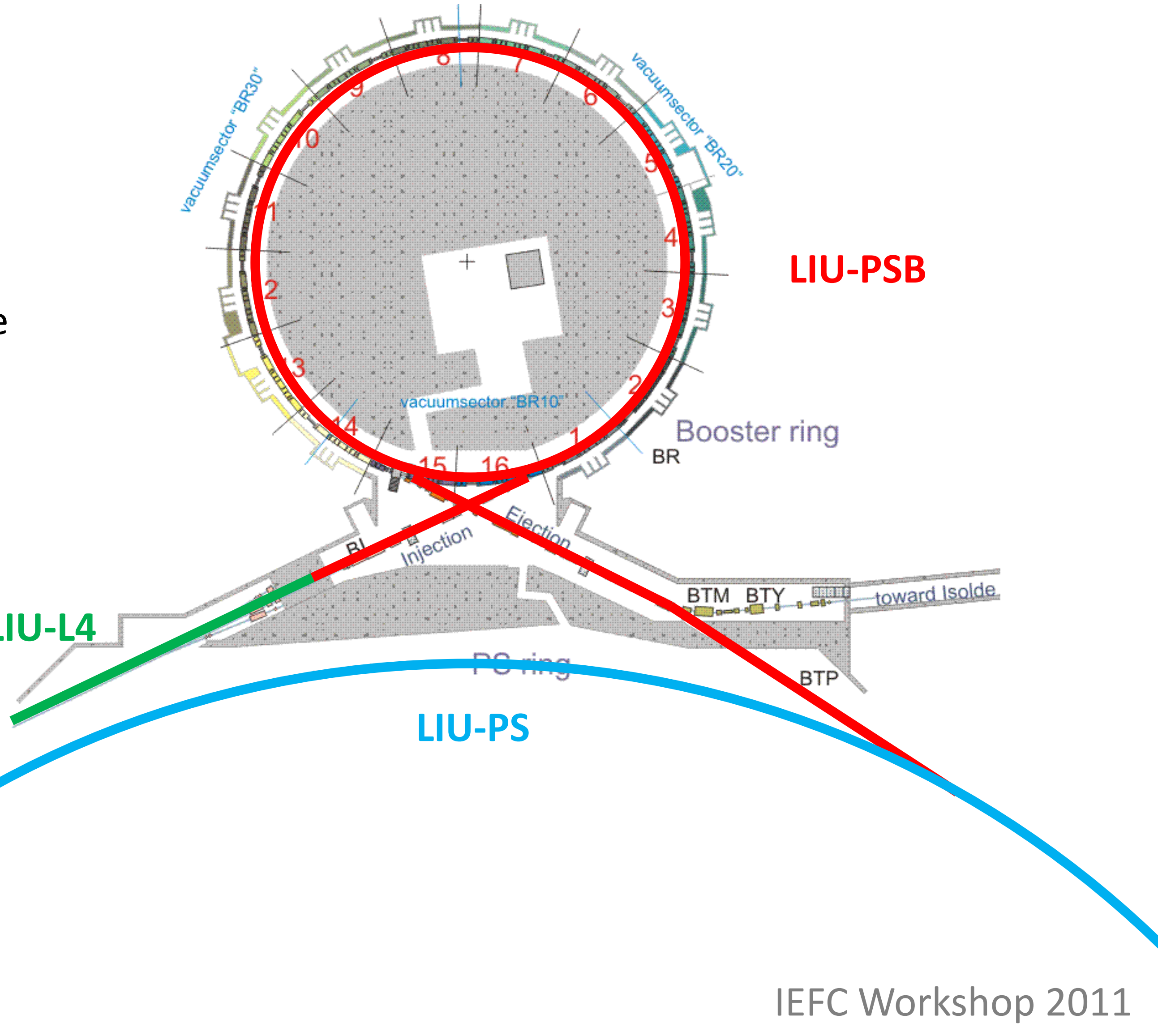
2 GeV Booster vs RCS



alternative locations outside the PS ring also being studied

PS Booster Upgrade

- upgrade of the BI line and injection region for 160 MeV H- & intensity increase
- upgrade of the Booster ring and the transfer line to the PS for 2 GeV



2.1	Management			Klaus Hanke
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	2.1.2	Safety		Nicolas Gilbert
	2.1.3	LARP collaboration		Eric Prebys
	2.1.4	Design Office		Ramon Folch
	2.1.5	Integration		Yvon Muttoni
	2.1.6	Optics Database		
	2.1.7	Layout Database		
		2.1.7.1	Equipment data	Sonia Bartolome
		2.1.7.2	Layout database model	Pascal Le Roux
	2.1.8	Consolidation and Shutdown work		Nicolas Gilbert
	2.1.9	LIU-PSBU meetings		Thomas Hermanns
		2.1.9.1	2010	Thomas Hermanns
		1.1.9.2	2011	Thomas Hermanns
2.2	PSB Beam dynamics			Christian Carli
	2.2.1	Ring beam dynamics		Christian Carli
	2.2.2	Exploitation of Energy Painting		Christian Carli
2.3	Magnets			Antony Newborough
2.4	RF systems			Alan Findlay
	2.4.1	RF cavities & Power		Mauro Paoluzzi
	2.4.2	LLRF		Maria-Elena Angoletta
	2.4.3	PSB Transverse Damper		Alfred Blas
	2.4.4	RF Controls		Andy Butterworth
2.5	Power Convertors			
	2.5.1	Booster injection		David Nisbet
	2.5.2	2 GeV upgrade		Serge Pittet
	2.5.3	RCS studies		Serge Pittet
2.6	Beam instrumentation			Jocelyn Tan
2.7	Beam Intercepting Devices			Oliver Aberle - Alternate Alessandro Massi
2.8	Vacuum System			Edgar Mahner
2.9	LINAC4 to PSB transfer line and PSB injection systems			
	2.9.1	Beam dynamics studies		Christian Carli
	2.9.2	Injection system equipment		Wim Weterings
2.10	PSB Extraction system and PSB-PS transfer line			
	2.10.1	Beam dynamics studies		Christian Carli
	2.10.2	Extraction and transfer line equipment		Jan Borburgh
2.11	Controls			Steen Jensen
2.12	Electrical Systems			Davide Bozzini, Slawomir Olek
2.13	Cooling and Ventilation			Mauro Nonis
2.14	Installation, Transport and handling			Ingo Rühl
	2.14.1	Transport and handling equipment		Ingo Rühl
	2.14.2	Transport and handling services (incl. feasibility studies)		Caterina Bertone
2.15	Civil Engineering			Luz Anastasia Lopez-Hernandez
2.16	Radiation Protection			Markus Widorski
	2.16.1	General RP		Markus Widorski
	2.16.2	RP studies		Markus Widorski
2.17	Interlock systems			Bruno Puccio
	2.17.1	WIC		Pierre Dahlen
	2.17.2	BIC		Benjamin Todd
2.18	Alarms			
2.19	Access Systems - Doors			
2.20	Survey			Tobias Dobers
2.21	Commissioning and Operation			Bettina Mikulec
2.22	Dismantling			

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The
PSB Upgrade
Working Group

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DATE: 2010-09-23

Feasibility Study

PS BOOSTER ENERGY UPGRADE FEASIBILITY STUDY FIRST REPORT

Abstract
This document summarises a survey of the CERN PS Booster systems with regard to a possible energy upgrade to 2 GeV. Technical solutions are proposed along with a preliminary estimate of the required resources and the time lines.

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Distribution List: R. Heuer

- double checked the arguments presented at the 2010 Chamonix workshop - confirm that an increase in beam energy will facilitate injection of high-brilliance and high intensity beams into the PS
- survey of all PSB equipment and systems with regard to an energy increase - did not find any showstopper
- identified PSB equipment and systems that need to be modified or exchanged in order to operate at 2 GeV beam energy
- propose technical solutions for these items, along with a cost estimate and schedule
- identified items, which were already accounted for in the consolidation program - disentangled these items from the budget estimate for the energy upgrade
- we propose a project schedule, which is in line with the long-term LHC planning

Expected Performance Gain with 2 GeV [G. Rumolo, LIU Day, Dec 2010]

PSB 2.0

- injection at 2GeV lowers space charge effect by a factor $(\beta\gamma^2)_{2GeV}/(\beta\gamma^2)_{1.4GeV} \approx 1.63$
  → can inject beams **~65% more** intense keeping the same space charge tune spread as now
- if we assume to conserve the longitudinal emittance (e.g., 1.3 eVs, LHC beam h=1), the bunch at 2GeV will be 33% shorter at the exit of the PSB, which would in principle limit the above gain to less than 40%; however, the PS bucket acceptance at injection also increases by 50%, which allows for injection of larger longitudinal emittances, recovering the desired gain (50% larger longitudinal emittance required)
- larger transverse emittances acceptable at the PS injection, if the final transverse emittances to the LHC are the same? Unlikely, as the previously PSB specified transverse emittances have meanwhile become the "nominal" LHC emittances!

→ at least 65% intensity increase (within constant emittance) expected

$$\Delta Q_x = \frac{R_p N_b}{(2\pi)^{3/2}\gamma^3\beta^2\sigma_z} \oint \frac{\beta_x(s)ds}{\sigma_x(s)\left[\sigma_x(s)+\sigma_y(s)\right]}$$

$$\Delta Q_y = \frac{R_p N_b}{(2\pi)^{3/2}\gamma^3\beta^2\sigma_z\sqrt{\epsilon_y}} \oint \frac{\sqrt{\beta_y(s)}ds}{\sigma_x(s)+\sigma_y(s)}$$

$$\begin{cases} \sigma_x(s) = \sqrt{\epsilon_x\beta_x(s) + D_x^2(s)\left(\frac{\delta p}{p_0}\right)^2} \\ \sigma_y(s) = \sqrt{\epsilon_y\beta_y(s)} \end{cases}$$

$$\epsilon_{x,y} = \frac{\epsilon_{xn,yn}}{\beta\gamma}$$

$1/\beta\gamma^2$ $1/\sigma_z$ $1/\varepsilon$

LHC Beams from the PSB with L4 and 2 GeV [B.Mikulec]

User	Description	Harmonic at extr.	PSB rings used	Intensity per ring	rms emittance at extr. [mm mrad]	Bunch length at extraction [ns]	Extr. energy [GeV]
LHC25A/B	25 ns LHC beam (double batch PS transfer)	1	1-4 and 3+4 (2 extractions)	2.43E12 (ultimate) and smaller	hor.: ≤2.5 vert.: ≤2.5	180	2
LHC25	25 ns LHC beam (single batch PS transfer)	2+1	2-4	3.25E12 (nominal) and smaller by factor 20	hor.: ≤2.5 vert.: ≤2.5	140	2
LHC50	50 ns LHC beam (single batch PS transfer)	2+1	2-4	for ultimate expect also 2.43E12 (2 bunches/ring)	hor.: ≤2.5 vert.: ≤2.5	140	2
LHC75	75 ns LHC beam (single batch PS transfer)	2+1	2-4	variable, but smaller than 25 and 50 ns	hor.: ≤2.5 vert.: ≤2.5	140	2
LHCPILOT	early LHC pilot beam	1	3	0.005E12	hor.: 2.5 vert.: 2.5	85	2
LHCPROBE	early LHC probe beam	1	3	0.005-0.023E12	hor.: ≤1 vert.: ≤1	70	2
LHCINDIV	individual bunch LHC physics beam	1	1-4	0.023-0.135E12	hor.: ≤2.5 vert.: ≤2.5	80-85	2

B. Mikulec / Commissioning

emittance values as specified today – can be reduced with Linac4

FT Beams from the PSB with L4 and 2 GeV [B.Mikulec]

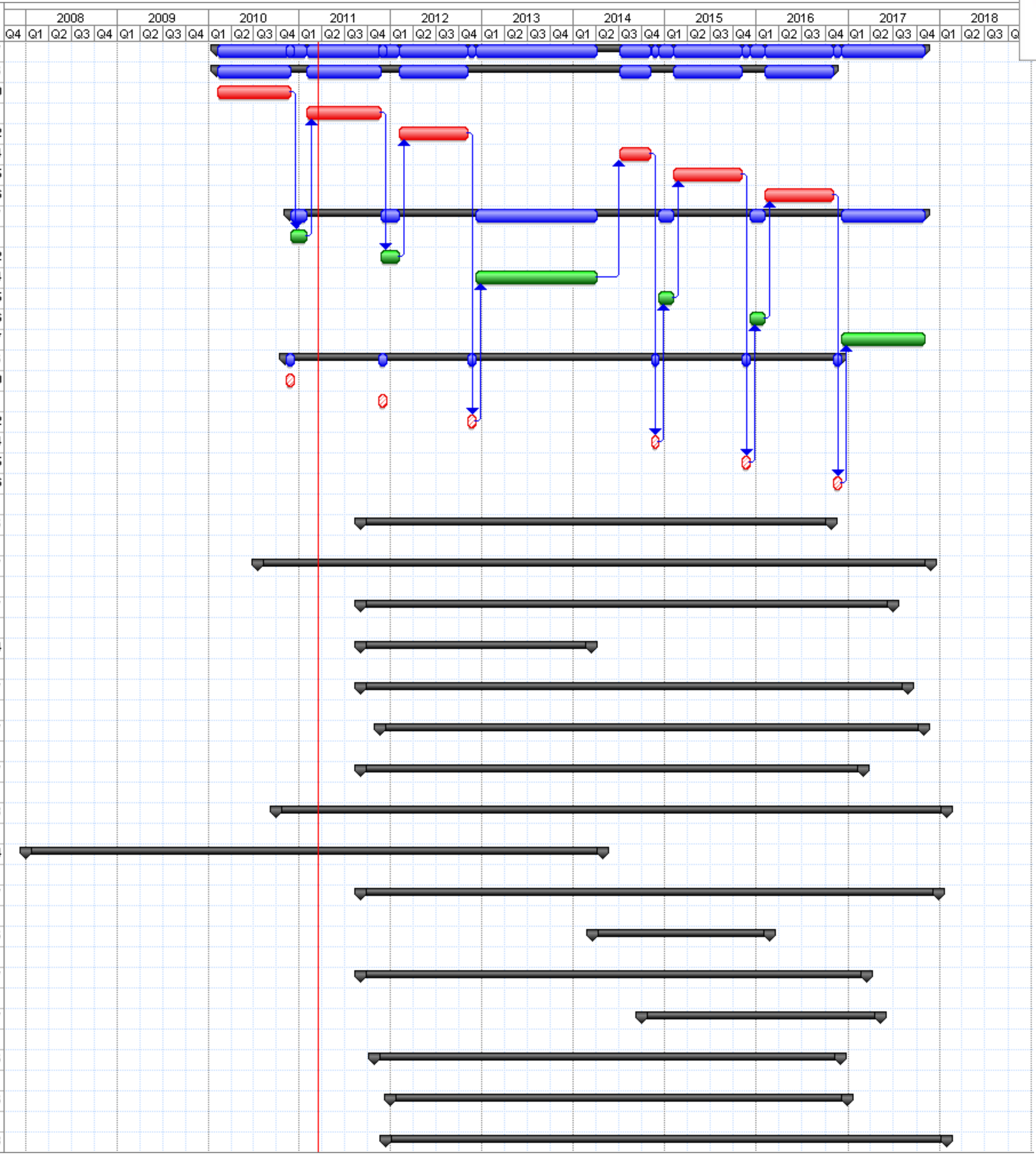
User	Description	Harmonic at extr.	PSB rings used	Intensity per ring	rms emittance at extr. [mm mrad]	Bunch length at extraction [ns]	Extr. energy [GeV]
CNGS	beam for CNGS target (until end of 2015?)	2	1-4	0.6-8E12 + ~45% increase to reach target limit	hor.: ~10 vert.: ~8 ~12/7 with MTE	180	2
SFTPRO	SPS fixed target beam	2	1-4	<6E12 – would an increase be desirable?	hor.: ~6-8 vert.: ~5-6 ~12/7 with MTE	180	2
AD	beam for AD target	1	1-4	4E12 (currently)	hor.: ~8 vert.: ~6	190	2
TOF	nTOF beam	1	1-4	<9E12 (currently)	hor.: ~10 vert.: ~10	230	2
EASTA/B/C	beam for the PS EAST area targets	1	3 (+2)	~0.1-0.45E12	hor.: ~3 vert.: ~1	150	2
NORMGPS NORMHRS	ISOLDE GPS/HRS target beams	1	1-4	up to 10E12 (currently – increase with HIE-ISOLDE?)	hor.: ≤15 vert.: ≤9	250	1 or 1.4
STAGISO	ISOLDE staggered beam for special targets	1	2-4	<3.5E12	hor.: <8 vert.: <4	230	1 or 1.4

B. Mikulec / Commissioning

maximum intensity fixed to 1.4E13 p/ring (5.6E13 total) due to magnet cooling and RF limitations
in principle Linac4 could deliver up to 1.6E14 ppp with 65 mA current and 400 μs pulse
no user known to us for such intensities

2 GeV Booster: Schedule

ID	Task Name	Duration	Start	Finish
1	**Operation and Shutdowns**	**2025 days**	**01.02.10**	**31.10.17**
2	**PSB Proton Operation**	**1764 days**	**01.02.10**	**31.10.16**
3	Proton Operation 2010	211 days	01.02.10	22.11.10
4	Proton Operation 2011	214 days	29.01.11	21.11.11
5	Proton Operation 2012	196 days	01.02.12	31.10.12
6	Proton Operation 2014	89 days	01.07.14	31.10.14
7	Proton Operation 2015	195 days	02.02.15	30.10.15
8	Proton Operation 2016	196 days	01.02.16	31.10.16
9	**PSB Shutdown**	**1814 days**	**23.11.10**	**31.10.17**
10	Xmas Break 2010/11	49 days	23.11.10	28.01.11
11	Xmas Break 2011/12	51 days	22.11.11	31.01.12
12	Shutdown 2013/14 (LS1)	346 days	03.12.12	31.03.14
13	Xmas Break 2014/15	45 days	01.12.14	30.01.15
14	Xmas Break 2015/16	44 days	01.12.15	29.01.16
15	Shutdown 2017 (LS2)	239 days	01.12.16	31.10.17
16	**LHC Ion Operation**	**1586 days**	**06.11.10**	**30.11.16**
17	Ion Run 2010	21 days	06.11.10	06.12.10
18	Ion Run 2011	23 days	12.11.11	12.12.11
19	Ion Run 2012	22 days	01.11.12	30.11.12
20	Ion Run 2014	20 days	03.11.14	30.11.14
21	Ion Run 2015	21 days	02.11.15	30.11.15
22	Ion Run 2016	22 days	01.11.16	30.11.16
23				
24	**WP 1 Beam Dynamics**	**1348 days**	**01.09.11**	**27.10.16**
28				
29	**WP 2 Magnets**	**1923 days?**	**19.07.10**	**24.11.17**
60				
61	**WP3 RF System**	**1523 days?**	**01.09.11**	**29.06.17**
73				
74	**WP 4 Beam Intercepting Devices**	**664 days**	**01.09.11**	**14.03.14**
81				
82	**WP 5 Power Converters**	**1565 days**	**01.09.11**	**28.08.17**
118				
119	**WP 6 Vacuum System**	**1551 days**	**22.11.11**	**31.10.17**
125				
126	**WP 7 Beam Instrumentation**	**1437 days**	**01.09.11**	**01.03.17**
129				
130	**WP 8 Commissioning and Operation**	**1917 days**	**01.10.10**	**31.01.18**
134				
135	**WP 9 PSB Injection**	**1652 days?**	**01.01.08**	**25.04.14**
227				
228	**WP 10 Extraction and Transfer**	**1652 days**	**01.09.11**	**27.12.17**
274				
275	**WP 11 Controls**	**506 days**	**17.03.14**	**22.02.16**
282				
283	**WP 12 Electrical Systems**	**1447 days**	**01.09.11**	**15.03.17**
288				
289	**WP 13 Cooling & Ventilation**	**681 days**	**01.10.14**	**10.05.17**
306				
307	**WP 14 Radio Protection, Safety**	**1332 days**	**27.10.11**	**30.11.16**
314				
315	**WP 15 Transport and Handling**	**1305 days**	**02.01.12**	**30.12.16**
329				
330	**WP 16 Survey**	**1602 days**	**13.12.11**	**31.01.18**



2 GeV Booster: Schedule

LS1:
- beam dump/beam stopper
- PSB injection
- transport/handling facilities

LS2:
- magnet upgrade
- MPS installation and commissioning
- upgrade kicker/septa transfer line
- upgrade electrical system
- upgrade cooling/ventilation

2 GeV Booster: Budget

	Spending Profile (subtracted consolidation items and Linac4 expenses)											
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	total
Total Beam Dynamics	0	0	10	10	10	10	10	0	0	0	0	50
Total Magnets	20	0	162.5	62.5	65	655	1080	90	0	0	0	2135
Total Magnetic Measurements	0	20	40	60	60	60	60	60	0	0	0	360
Total RF	0	0	0	0	0	0	0	0	0	0	0	0
Total Beam Intercepting Devices	0	25	41	50	50	25	25	25	0	0	0	241
Total Power Converters (PSB)	0	0	765	545	5670	6300	1560	1160	0	0	-2000	14000
Total Power Converters (Injection)	0	330	1045	105	0	0	45	45	0	0	0	1570
Total Vacuum System	0	0	387	281	0	0	0	0	0	0	0	668
Total Beam Instrumentation	0	0	0	57	0	0	0	0	0	0	0	57
Total Commissioning	0	0	0	0	0	0	0	75	75	0	0	150
Total Injection	0	1000	1000	1500	2125	1500	1000	154	0	0	0	8279
Total Extraction, Transfer	0	0	0	360	996	748	444	0	0	0	0	2548
Total Controls	0	0	0	0	0	0	0	500	0	0	0	500
Total Electrical Systems	0	0	1100	500	0	0	0	100	0	0	0	1700
Total Cooling & Ventilation	0	0	0	0	0	0	100	900	0	0	0	1000
Total RP and Safety	0	0	0	0	0	0	0	0	0	0	0	0
Total Transport and Handling	0	0	0	25	25	0	30	200	0	0	0	280
Total Survey	0	5	0	25	5	5	0	10	0	0	0	50
Total per Year	20	1380	4550.5	3580.5	9006	9303	4354	3319	75	0	-2000	33588
Integrated Budget	20	1400	5950.5	9531	18537	27840	32194	35513	35588	35588	33588	

33588 = 54776,5 (total) – 20348,5 (cons.) – 840 (already paid by L4)

consolidation: items that are required for the 2 GeV to work (e.g. Booster RF, dump, …)

Linac4 injection: transferred from Linac4 project to LIU-PSB, added to budget, partly paid

→ **entered into MTP**

since Chamonix 2011:

- RCS option to replace the Booster
- would make both consolidation and upgrade obsolete
- work on 2 GeV Booster suspended
- RCS feasibility study and rough cost estimate launched (conclusions by summer 2011)
- if found competitive, more detailed study

RCS task force set up to reinforce the Booster Upgrade WG
investigate general parameters (parameters, lattice, size, apertures, location)
look only at potential cost drivers: magnets, power, civil engineering.

RCS: Suggested Parameter Table

Energy range	160 MeV to 2 GeV
Circumference	(200/7) π m ≈ 89.76 m
Repetition rate	~10 Hz
RF voltage	60 kV
Harmonics	h = 2 or 3
Frequency range	3.48 MHz (h=2 at injection) to 9.5 MHz (h=3 at ejection)
Beam parameters for LHC (for lower emittances scale down intensity accordingly)	Intensity: up to 12×2.7 10^{11} protons/cycle Transv. emittance: $\varepsilon^*_{rms} \approx 2.5\ \mu m$ Long. emittance: ε_l < 12×0.27 eVs (determined by acceptance for most cases)
Lattice	FODO with 15 cells and 3 periods, 4 cells in arc, straight with one cell
Tunes	$4 < Q_{H,V} < 5$
Relativistic gamma at transition	~4
Bending magnet filling factor	56 %
Maximum magnetic field	1.16 T

assume shortest option

h = 3 to fill 18 out of 21 PS buckets
h = 2 to fill 12 out of 14 PS buckets

C. Carli, Chamonix 2011

RCS: Beams & Parameters

LHC beams:
2.7E11 protons/LHC bunch (estimate for 2 GeV Booster with L4, M.Giovannozzi Chx. 2010)
→ have to deliver intensity for 12 LHC bunches per cycle → 12 x 2.7E11 ppp

high intensity beams:
assume maximum 1E13 ppp

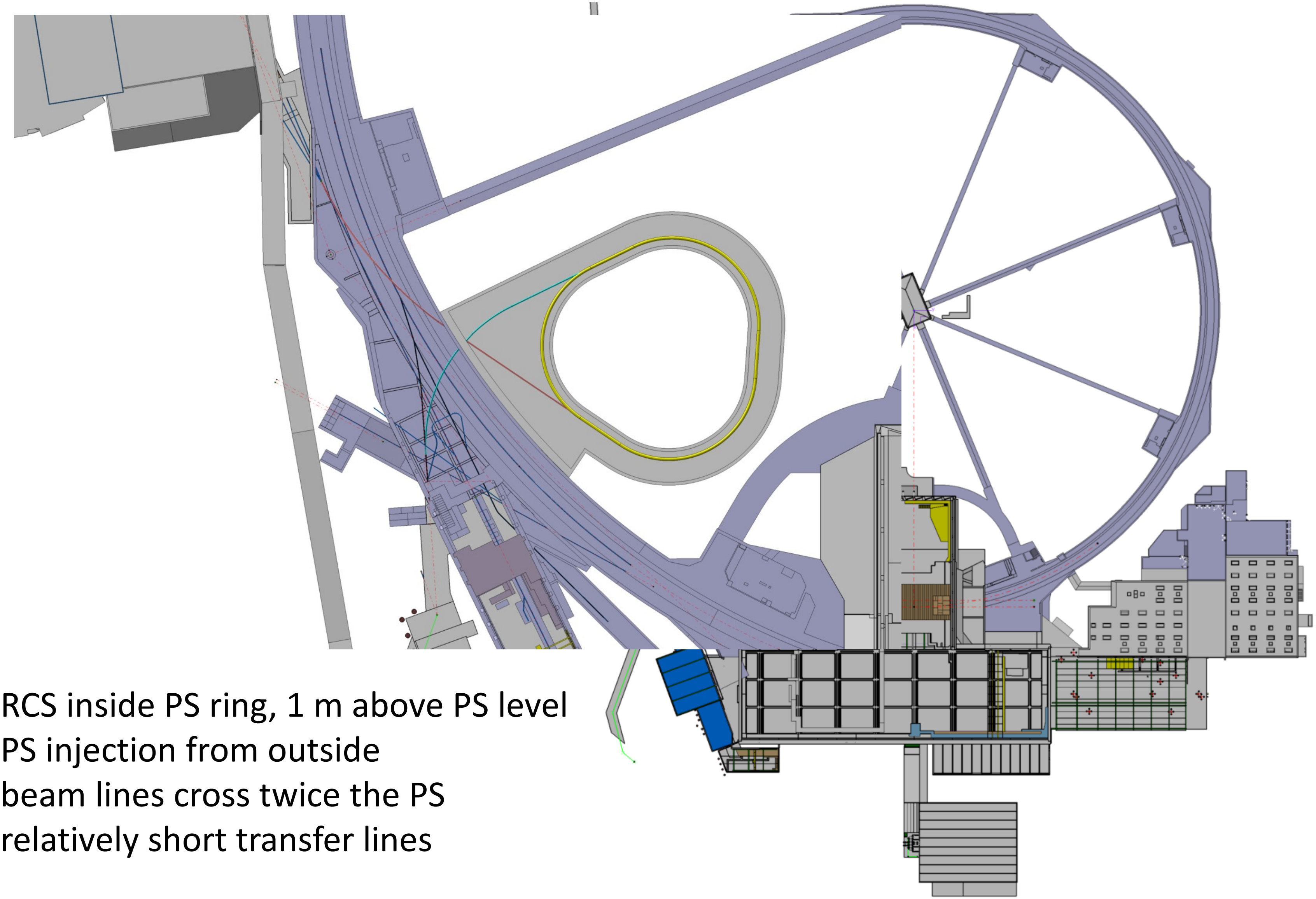
to be iterated with the high-intensity users ISOLDE, CNGS, …

machine parameters:
starting point Chamonix 2011 table, lattice and magnetic cycle have been iterated since (C. Carli)

lattice → beam size → aperture → magnet model → main power supply

should allow to get a rough estimate for feasibility and cost drivers; no details.
must not forget modifications to Linac4 in order to run at 10 Hz

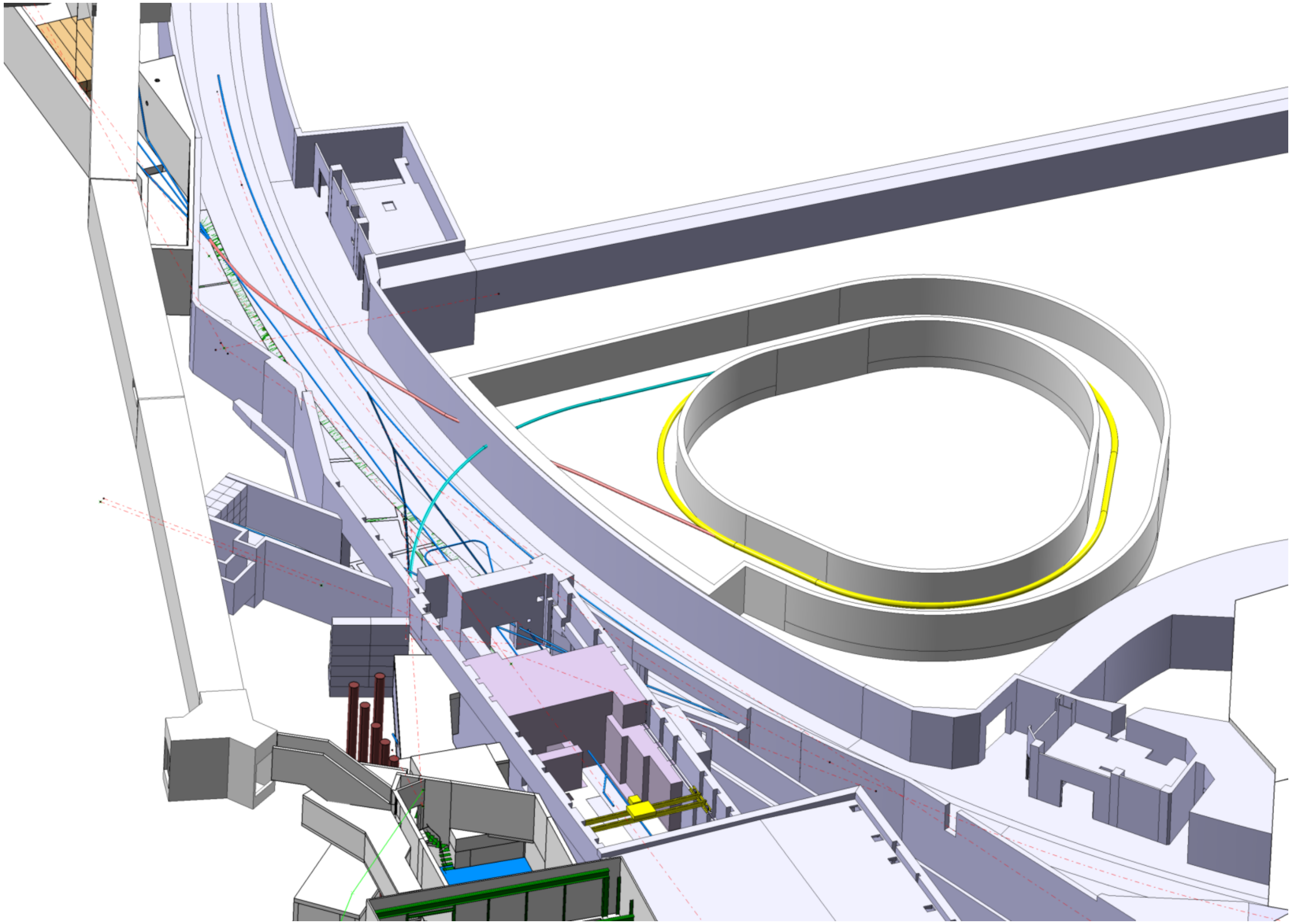
RCS: Location inside PS (Chamonix Suggestion)



- RCS inside PS ring, 1 m above PS level
- PS injection from outside
- beam lines cross twice the PS
- relatively short transfer lines

A. Kosmicki, L.A. Lopez-Hernandez

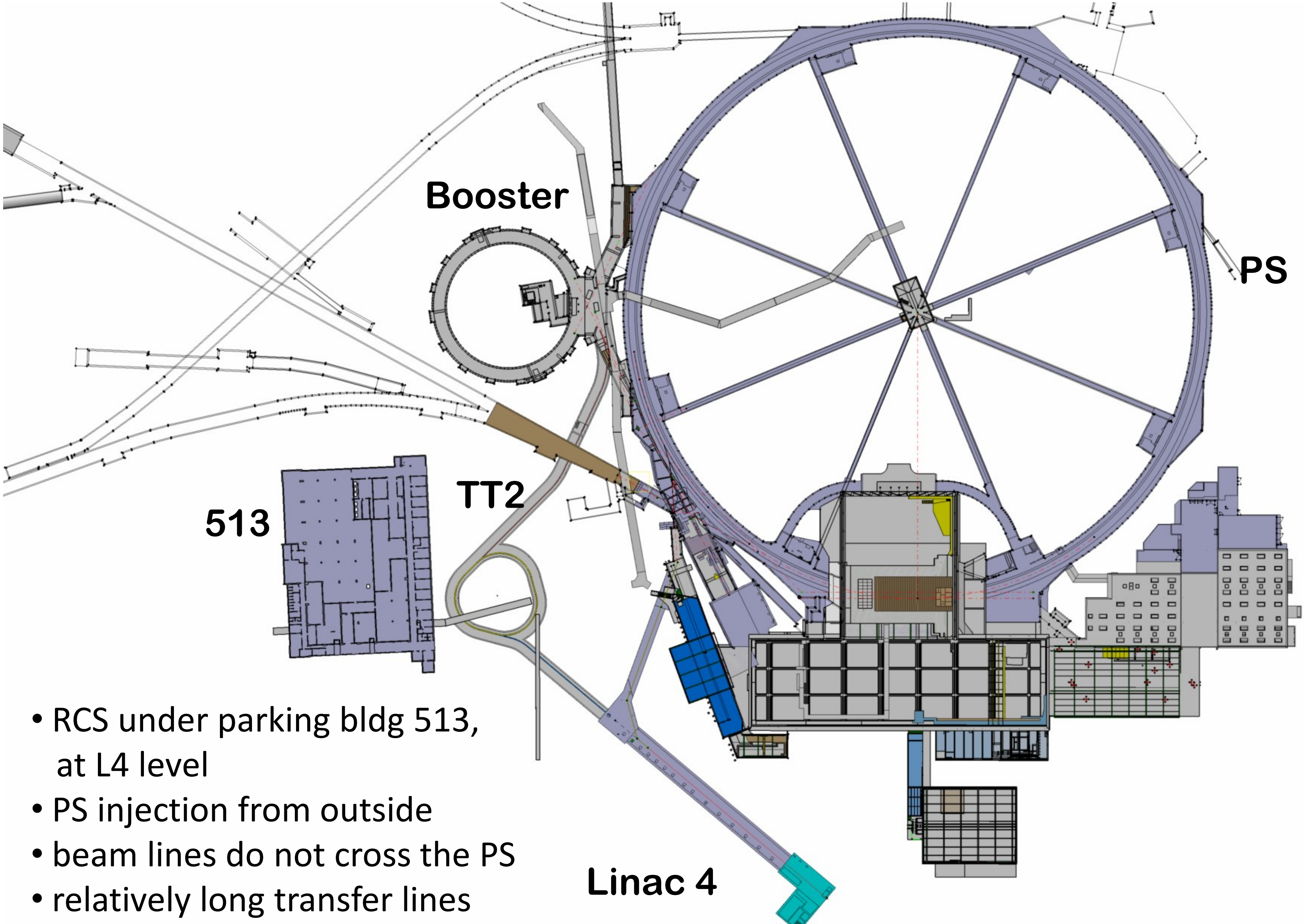
RCS: Location inside PS



- beam Lines cross twice the PS
- stray fields expected to be an issue
- passing under the PS would have to be very deep, estimated minimum 10 m (involving pits ~25 m below ground level)

A. Kosmicki, L.A. Lopez-Hernandez

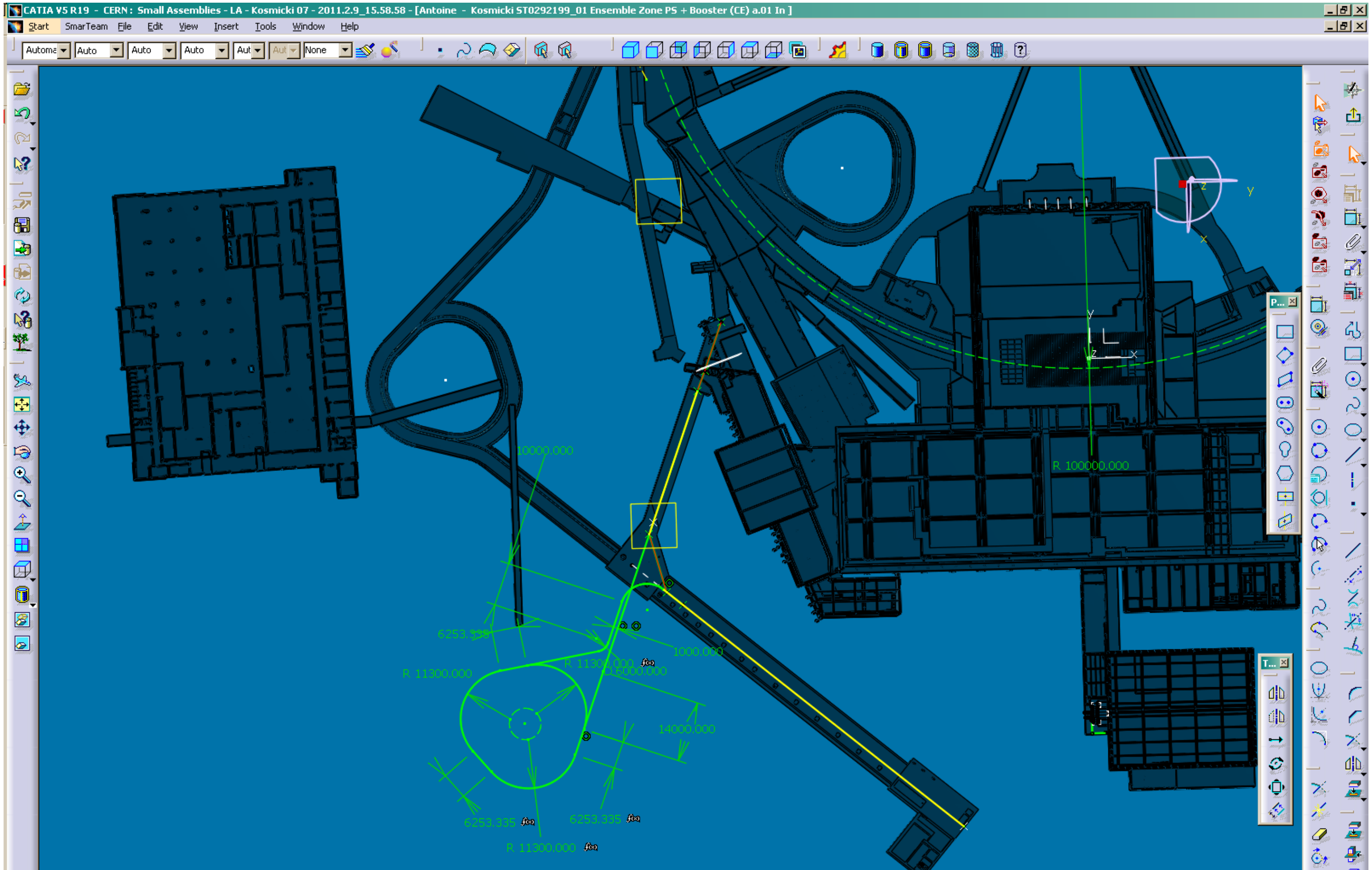
RCS: Location Parking Bldg 513



- RCS under parking bldg 513, at L4 level
- PS injection from outside
- beam lines do not cross the PS
- relatively long transfer lines
- RP issues probably OK

A. Kosmicki, L.A. Lopez-Hernandez

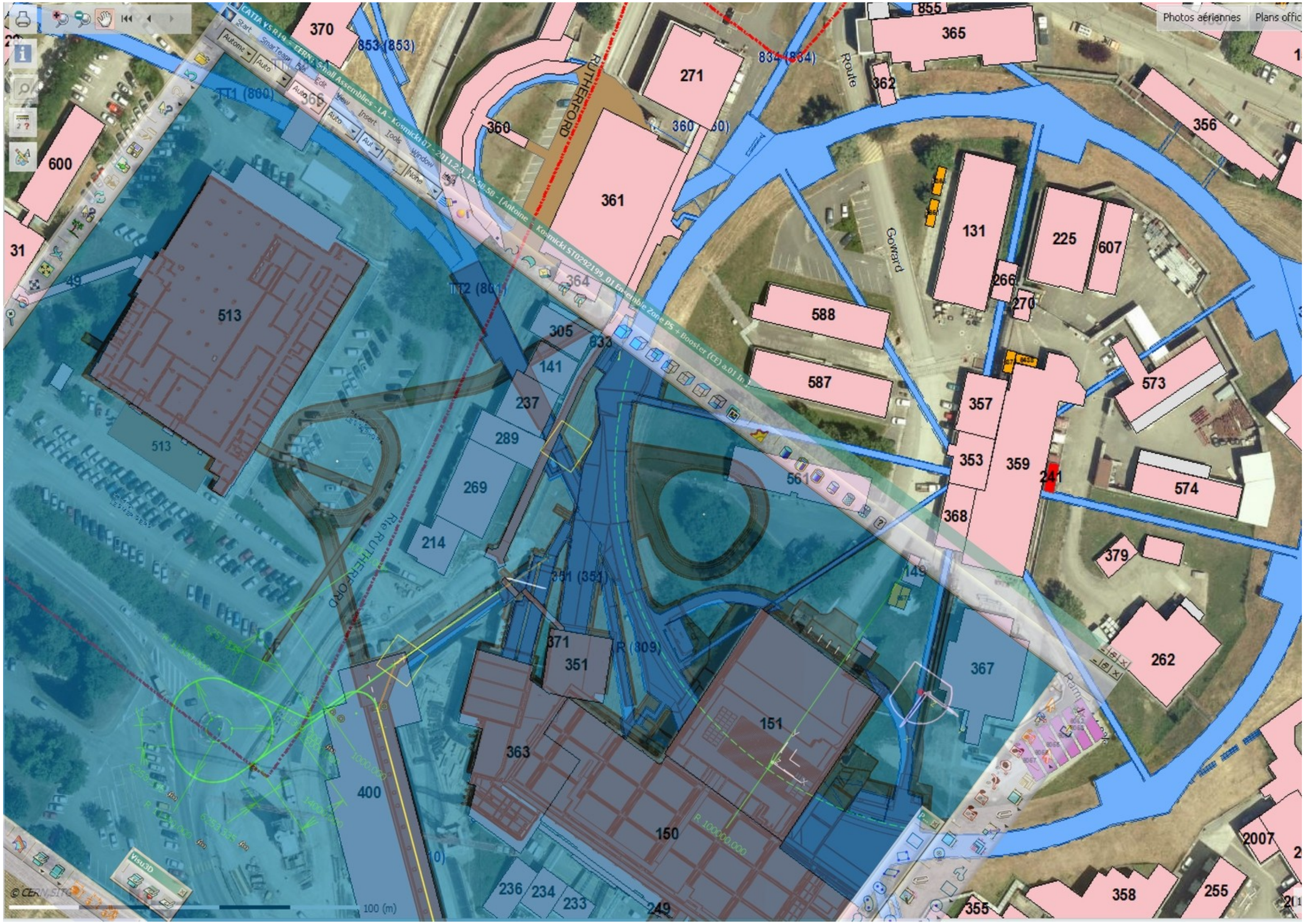
RCS: Suggested Location closer to L4 (Roundabout Scenario)



- RCS right downstream of L4 at L4 level
- PS injection from outside
- beam lines do not cross the PS
- re-use L4-PSB transfer line, must re-assess from an RP point of view, but looks feasible

B.Goddard, A.Kosmicki

RCS: Comparison of all Locations



Summary

Booster Energy Upgrade well advanced
- transformed from a task force into a project
- Linac4 injection has been added (from L4 project), PS injection has been transferred (to LIU-PS project)
- presented at Chamonix 2011, ready to go
- budget entered in MTP
- since Chamonix 2011 on hold, apart from the H- injection where work continues (in particular in view of a possible connection during LS1)

RCS option being looked into
- looking only into key issues, parameter space, civil engineering, magnets, power, RP
- Booster Upgrade Working Group reinforced
- feasibility and rough (!) cost estimate by early summer