The LIU-PSB Project

K. Hanke
for the PSB Upgrade WG

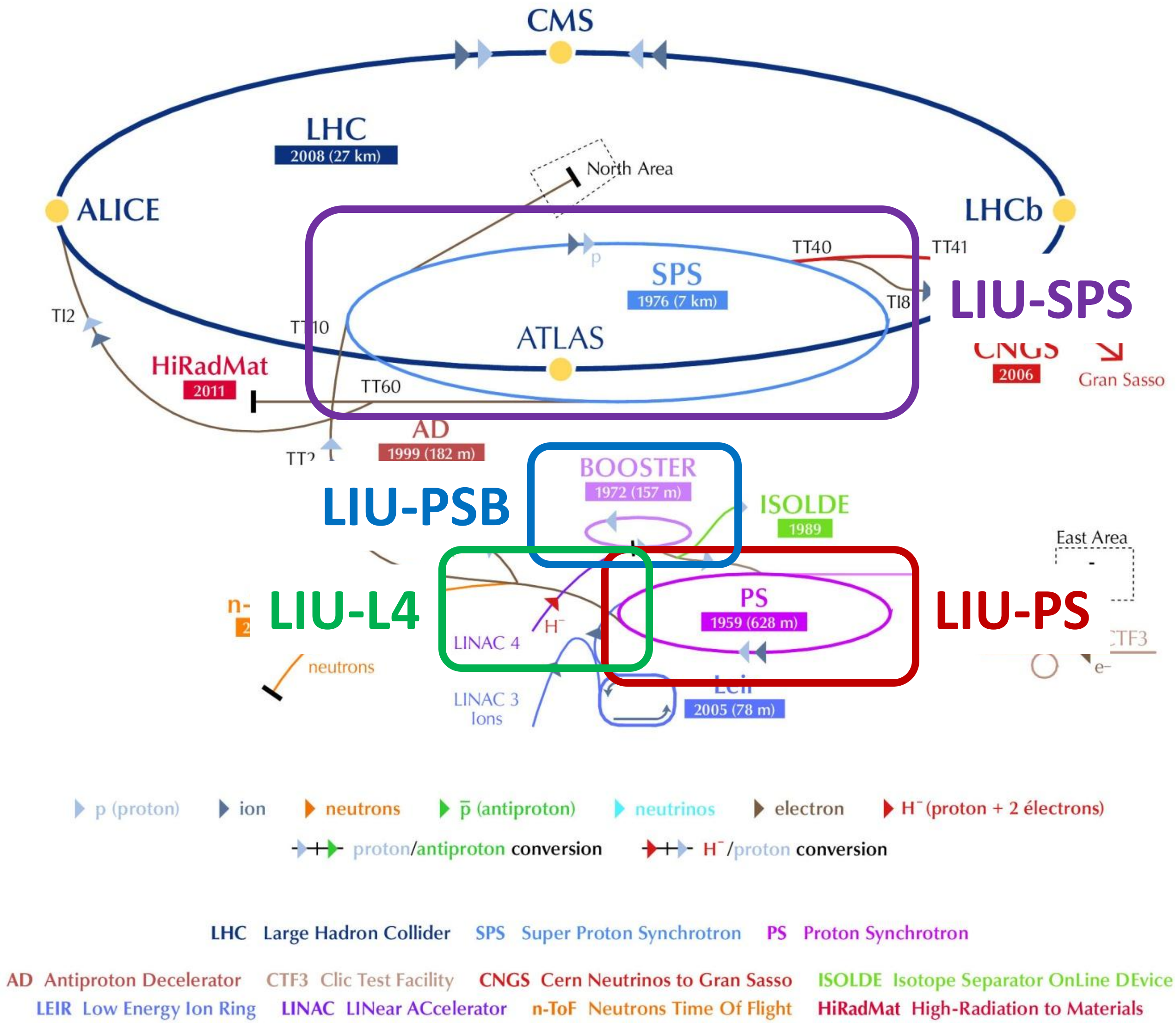
SGUI 02/02/12

The LIU Project

The LHC Injectors Upgrade Project (LIU) has been put in place to propose and implement the means for:

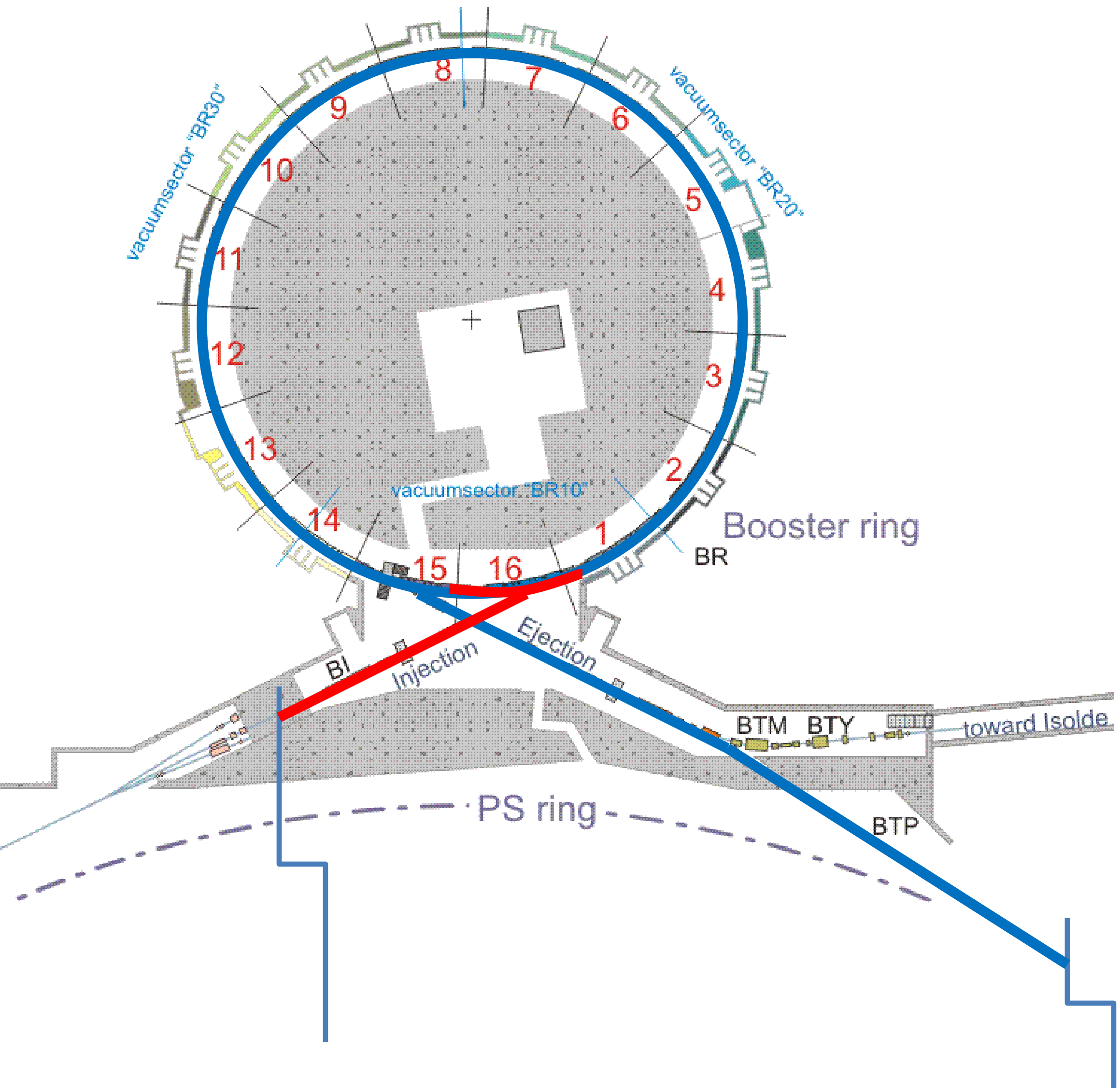
- allowing LHC & HL-LHC to reach their maximum potential for physics
- ensuring a reliable operation of the LHC for physics until the end of its life (≥ 2030 taking into account possibilities of LHeC & HE-LHC…)
- proper use of resources (> 150 MCHF material budget and > 300 man.years) with unavoidable interferences with other priorities of the organization

The LIU Project



Scope of LIU-PSB

PSB Upgrade
LIU Project



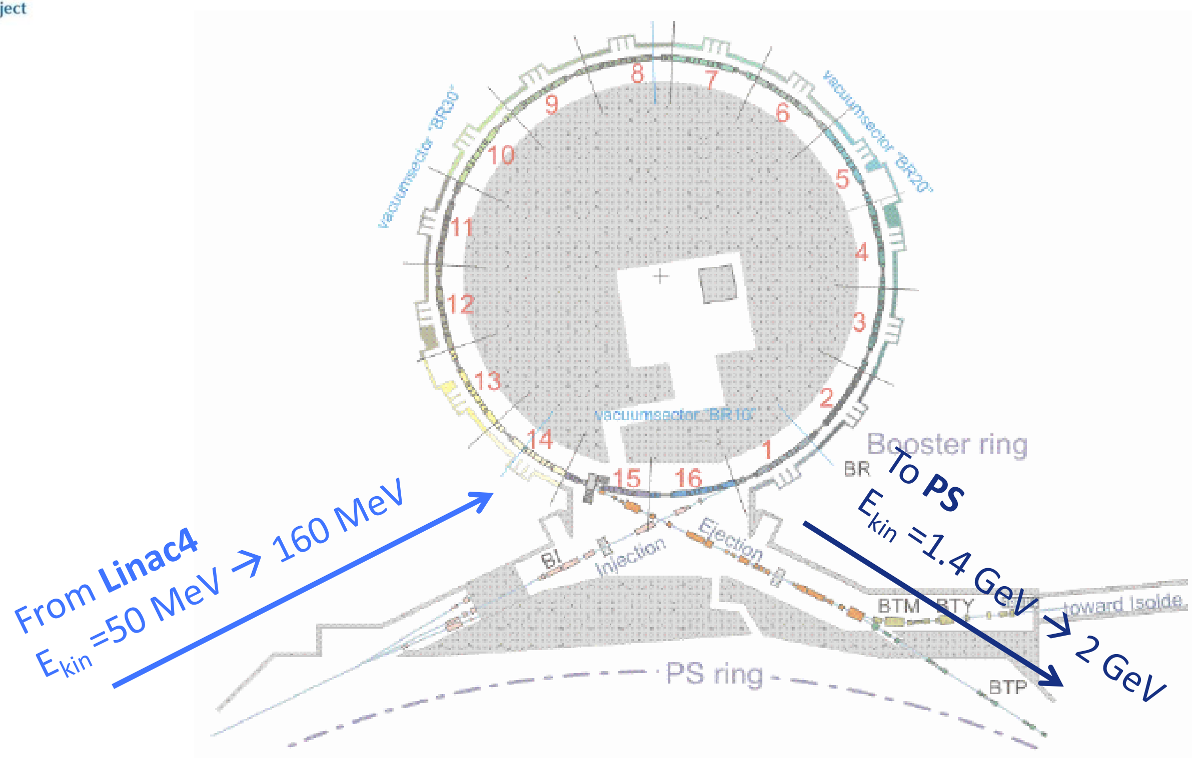
upgrade of the injection from 50 MeV protons to 160 MeV H- and increased intensity

- re-build injection line for 160 MeV
- replace injection septum by stripping foil
- injection bumps
- diagnostics
- …

upgrade of rings and extraction / transfer from 1.4 GeV to 2.0 GeV and increased intensity

- replace main power supply, number of smaller power supplies, magnets, kickers, etc.

High Brightness Beams for LHC



1. Linac4 will allow for production of higher brightness beams in the PSB
   → higher injection energy (160 MeV)
   → H^- injection
2. higher extraction energy into the PS (2 GeV)
   → eases PS injection (weaker space charge, transversely smaller beams)

Why rebuilding the Injection Region

PSB Upgrade LIU Project

- increased energy from 50 MeV to 160 MeV with Linac4

→ reduce space-charge effects at PSB injection

- injection of H- ions rather than protons

→ significantly reduce injection losses (at the moment about 50% of the beam is lost on the injection septum!)

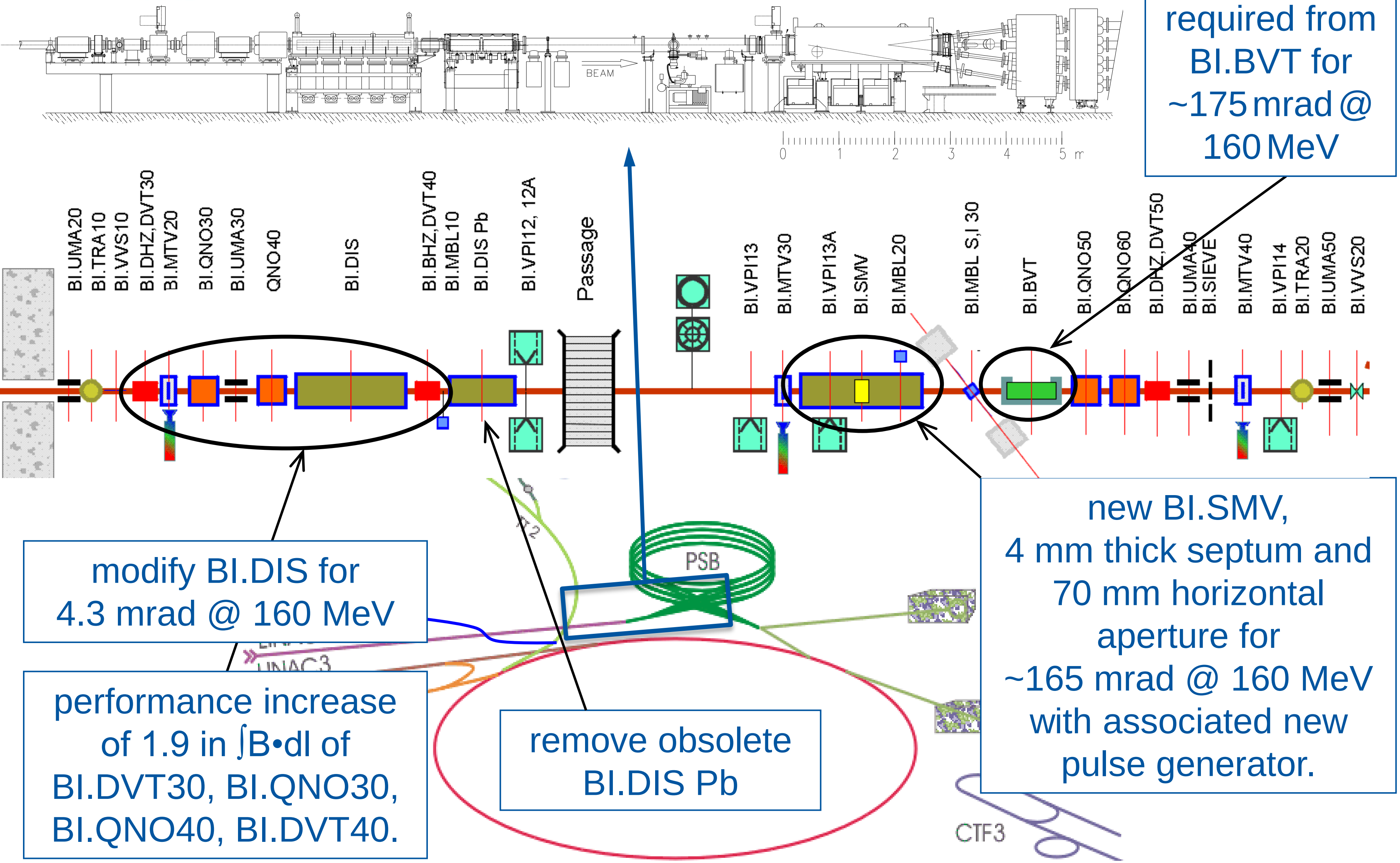
→ more flexibility in tailoring emittances by transverse phase space painting

		Ring 1		Ring 2		Ring 3		Ring 4		Sum		
0	LTB.BCT60	1873		1826		1852		1903		7438		
1	BI.BCT10	1820	97 %	1773	97 %	1831	99 %	1884	99 %	7293	98 %	0
2	BI.BCT20	1640	90 %	1601	90 %	1604	88 %	1654	88 %	6500	89 %	1
3	Injection	1008	61 %	1075	67 %	982	61 %	915	55 %	3981	61 %	2
4	Capture	838	83 %	959	89 %	905	92 %	816	89 %	3519	88 %	3
5	Accel.	631	75 %	918	96 %	871	96 %	693	85 %	3113	88 %	4
6	BT.BCT.00									3121	100 %	5
7	BTP.BCT.00									1	0 %	6
8	BTM.BCT.00									10	0 %	6
9	BTY.BCT112									NaN	□	6
10	BTY.BCT.213									2910	□	9
11	BTY.BCT.325									4	□	9

SGUI 2-Feb-2012

Injection Region for 160 MeV

PSB Upgrade
LIU Project



~0.36 Tm required from BI.BVT for ~175 mrad @ 160 MeV

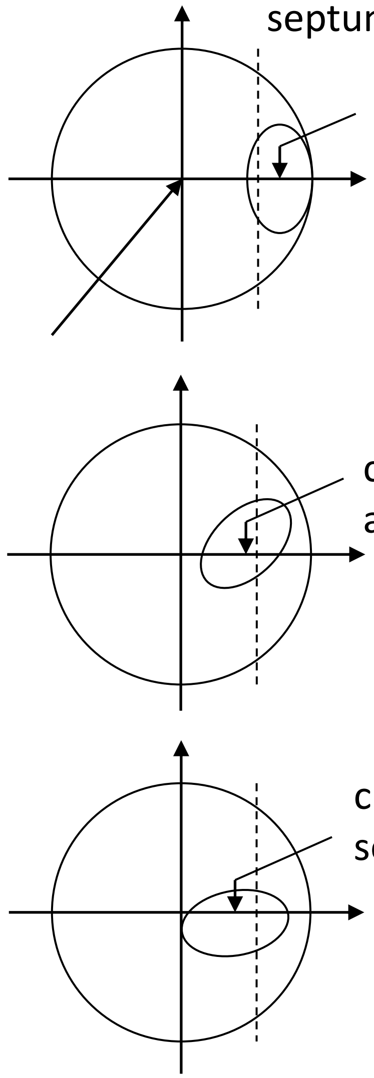
new BI.SMV, 4 mm thick septum and 70 mm horizontal aperture for ~165 mrad @ 160 MeV with associated new pulse generator.

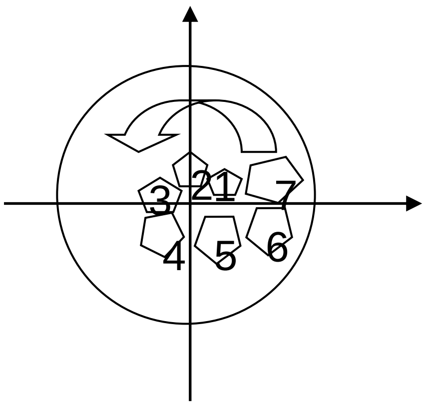
modify BI.DIS for 4.3 mrad @ 160 MeV

performance increase of 1.9 in ∫B•dl of BI.DVT30, BI.QNO30, BI.QNO40, BI.DVT40.

remove obsolete BI.DIS Pb

Present Multiturn Injection



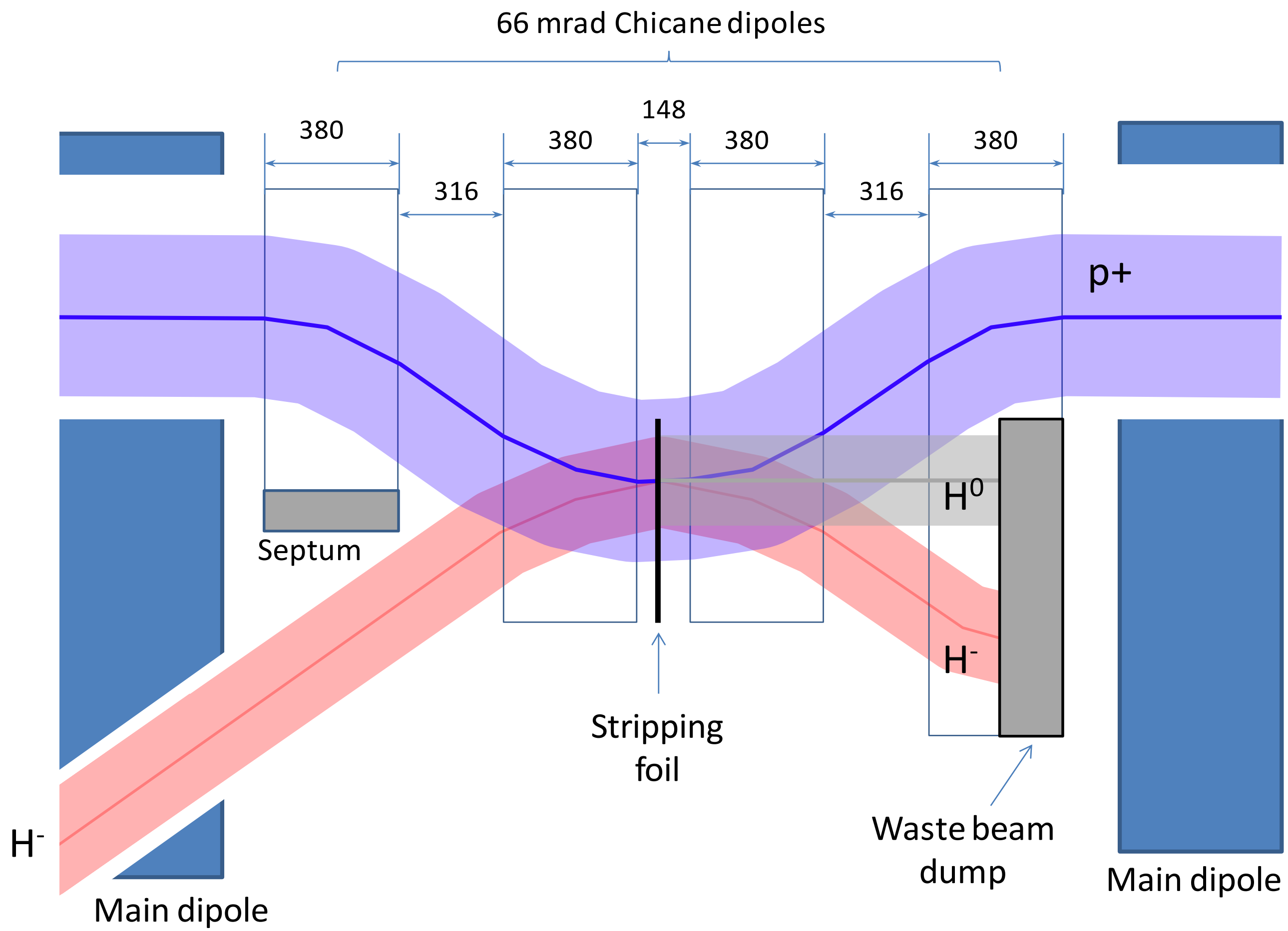


as this process takes place, subsequent linac beam “slices” are injected, with increasing oscillation amplitude around the instantaneous closed orbit (“horizontal stacking”)

beamlets are now “polygons”, as they have undergone several cuts

they spiral up around the (moving) closed orbit, leading to a density distribution which is dense in the core and less dense in the outer part

Charge Exchange Injection

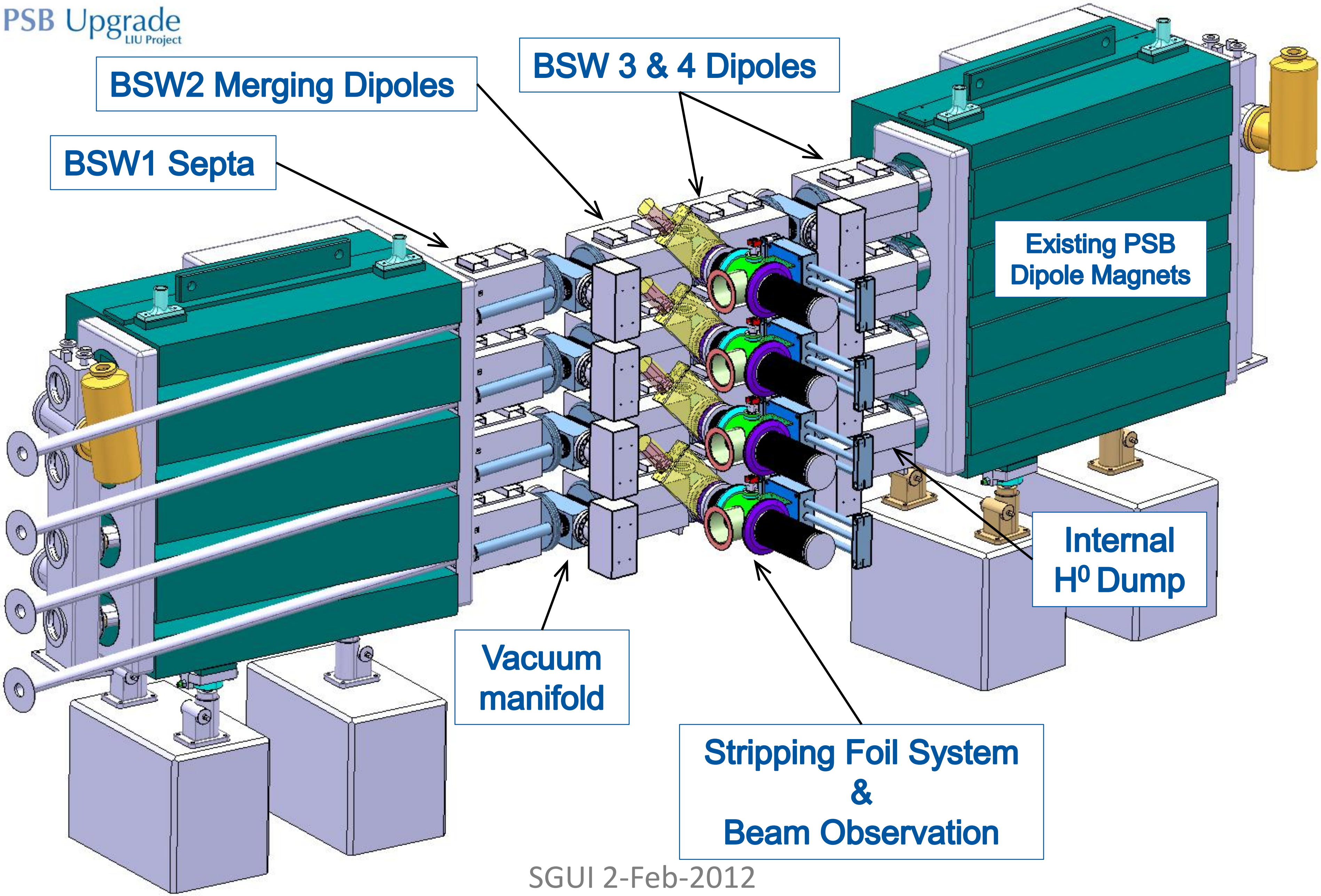


more technical details:

→ review held 9-10 November, see

https://indico.cern.ch/conferenceTimeTable.py?confId=158153#20111109

Injection Region Lay Out



PSB Upgrade
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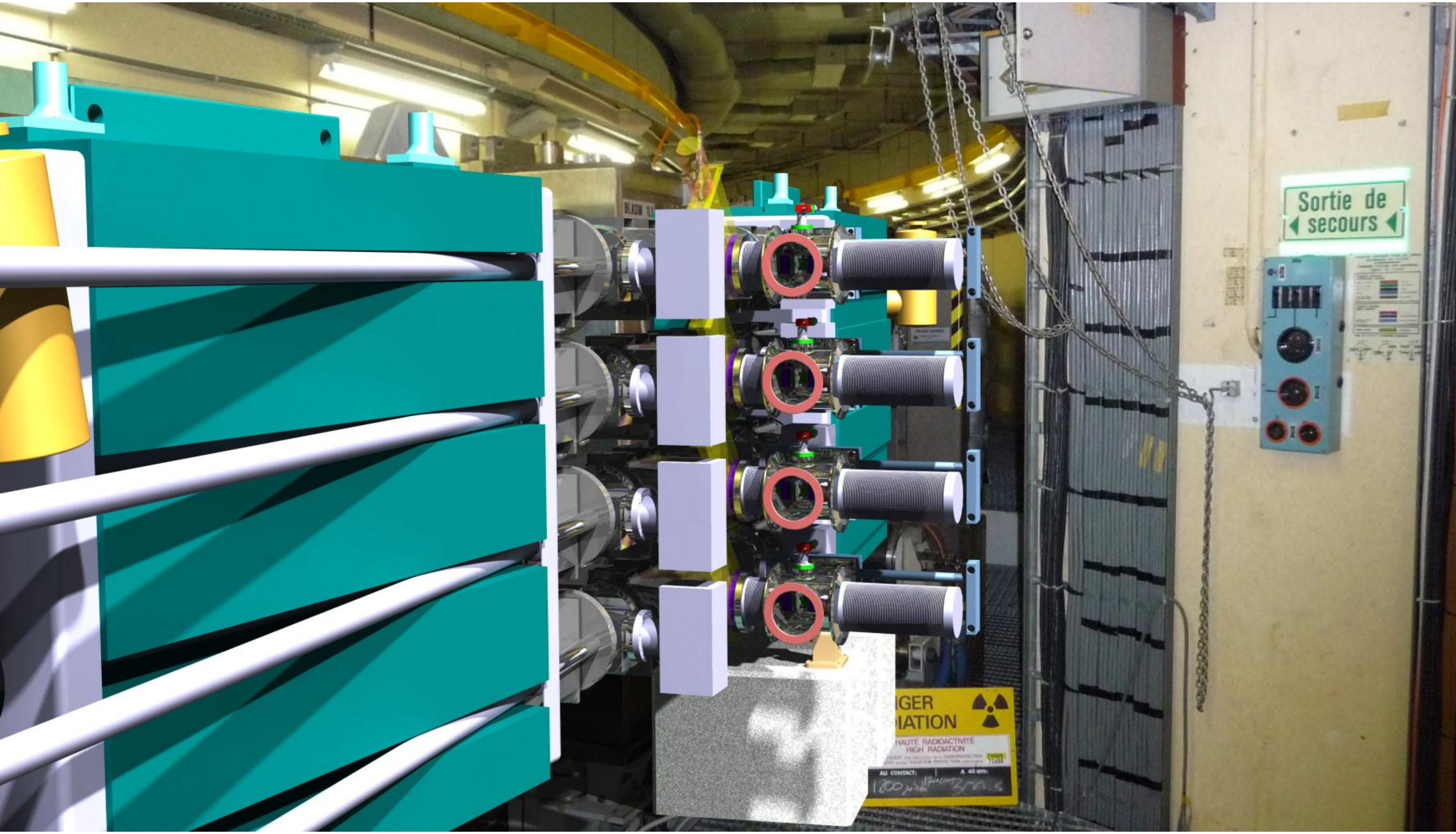
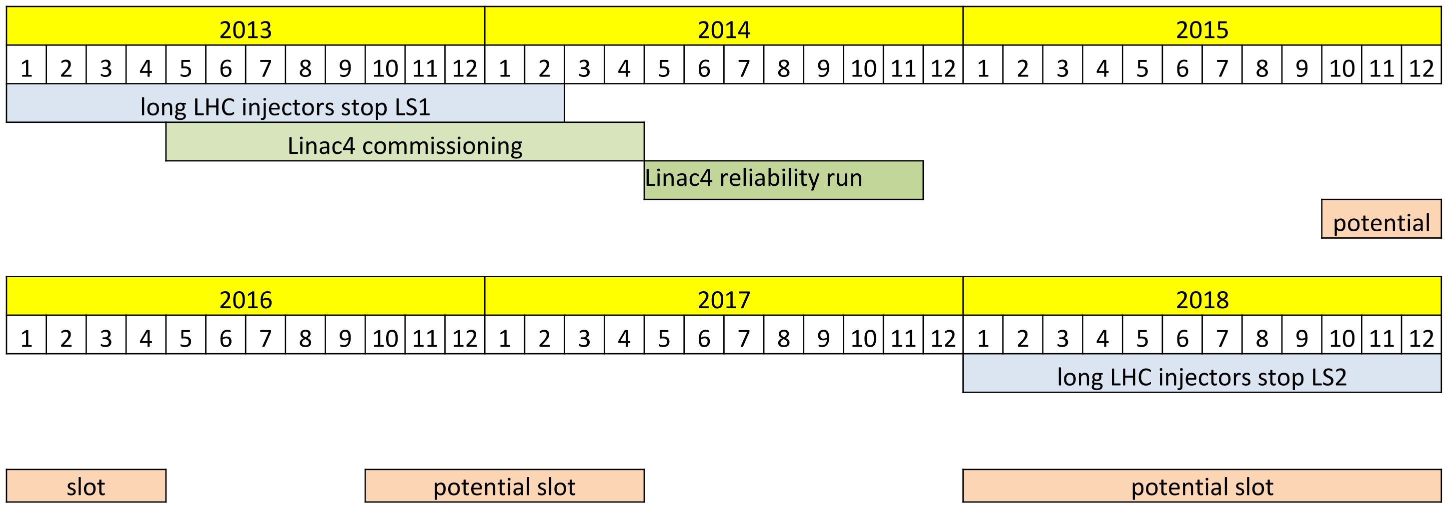
Present and Future Injection Region

B. Goddard, Review on PSB 160 MeV H^{-} Injection, 9-10 November 2011



Booster Injection Planning

PSB Upgrade LIU Project



1. Connection of Linac4 to the PSB during LS1 ruled out
2. Connect to the PSB during an intermediate length shut-down ("LS1.5")
3. Connect to the PSB during LS2 (presently assumed in 2018)

hope to know more after Chamonix 2012
detailed planning being worked on

Upgrade of the Booster to 2.0 GeV

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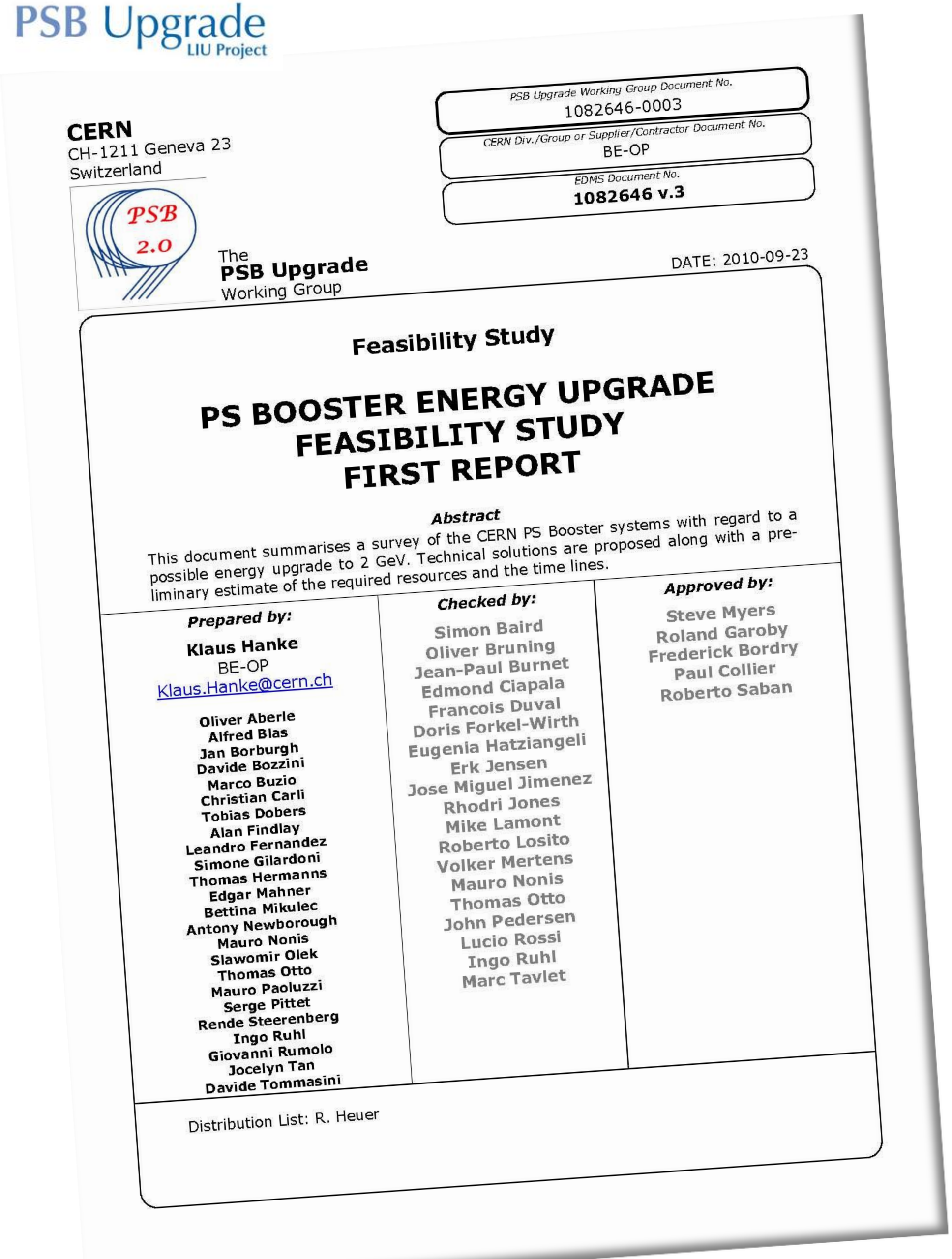

CERN
CH-1211 Geneva 23
Switzerland

PSB Upgrade Working Group Document No.
1082646-0003

CERN Div./Group or Supplier/Contractor Document No.
BE-OP

EDMS Document No.
1082646 v.3

The
PSB Upgrade
Working Group

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

study launched following Chamonix 2010
→ feasibility, cost & time lines confirmed
RCS alternative studied following Chx. 2011
→Booster option retained

3rd energy upgrade:
- from 800 MeV to 1 GeV (1988)
- from 1 GeV to 1.4 GeV (1999)
- from 1.4 GeV to 2.0 GeV (LS2)

- no technical showstoppers identified
- however a number of equipment and
- systems need to be changed or upgraded
- high-impact items: MPS, RF, kickers, septa, …

Expected Performance Gain with 2.0 GeV

PSB Upgrade LIU Project

LASLETT TUNE SHIFT

$$\Delta Q_{x,y} = \frac{r_p N_b}{(2\pi)^{\frac{3}{2}} \gamma^2 \beta \sigma_z} \oint \frac{\beta_{x,y}(s) ds}{\sqrt{\epsilon_{x,y}\beta_{x,y}(s)}(\sqrt{\epsilon_x \beta_x(s)} + \sqrt{\epsilon_y \beta_y(s)})}$$

if we assume that:

⇒ the optics at the PS injection remains the same

⇒ the bunch length does not change

$$\frac{(\gamma^2\beta)_{2\,\mathrm{GeV}}}{(\gamma^2\beta)_{1.4\,\mathrm{GeV}}} = 1.63$$

⇒

$\frac{N_b}{\epsilon_x \epsilon_y}$ up to 63% larger

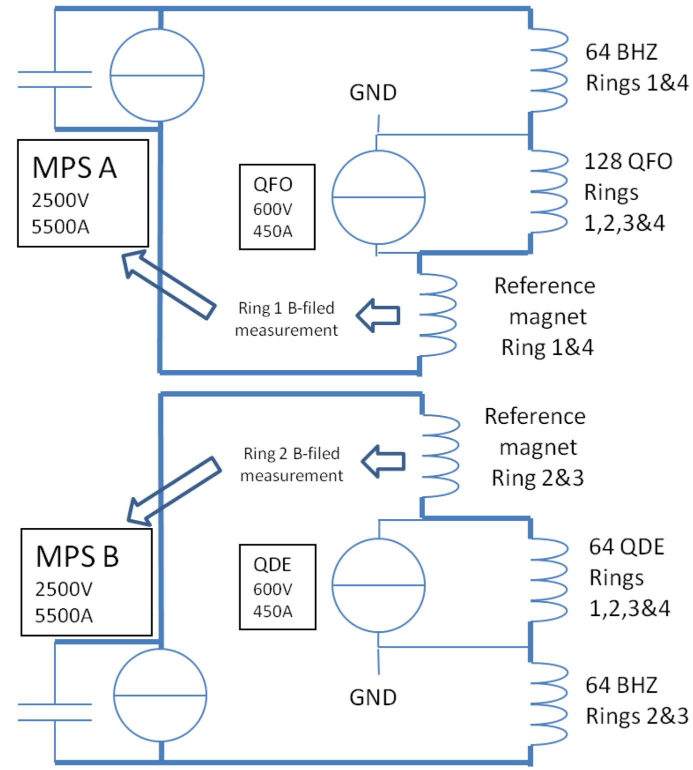
G. Rumolo

Main Power Supply

PSB Upgrade LIU Project

physics		LS1	physics				LS2	physics
2011	2012	2013	2014	2015	2016	2017	2018	2019

- Alternative with new magnet studied
- Design baseline confirmed and refined
- Specification ready for submission
- Market survey and call for tender completed
- Converter manufactured and installed
- Converter system commissioned
- Converter commissioned and ready for operation

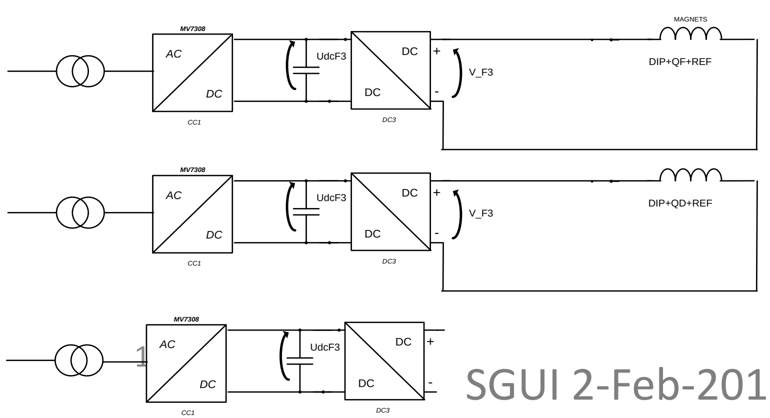


Benefits

- Overall voltage available increases and would allow a reduction of the RMS current using a faster ramping.
- The capacitor bank totally absorbs the peak power on the 18kV network. Meyrin SVC would then become optional.
- Spare sharing between MPS A and B and eventually with POPS.
- Only a few new cables needed between the reference magnet (BCER) and the MPS.
- New B-field regulation to minimize eddy currents and saturation effects impact at higher current and acceleration rate.

Drawbacks

- Cost.



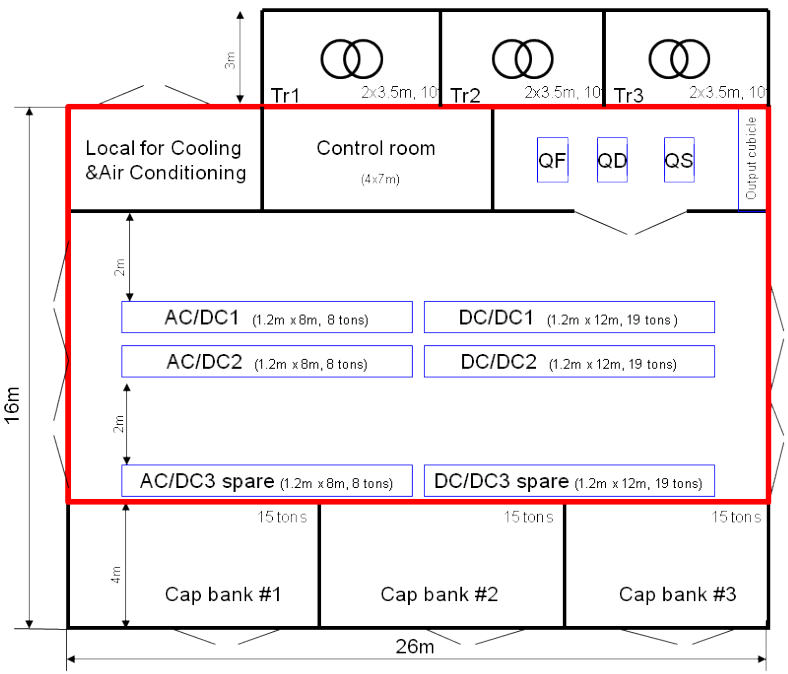
S. Pittet

Main Power Supply

PSB Upgrade LIU Project

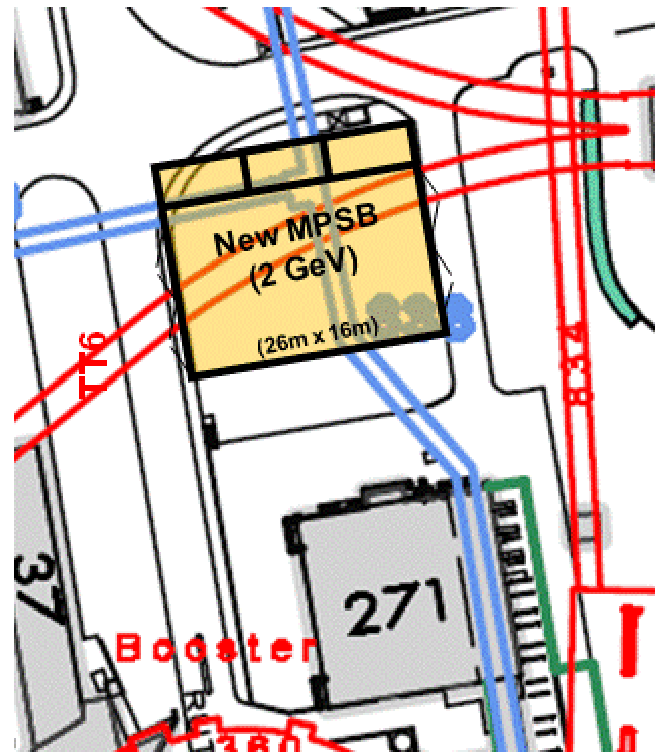
physics		LS1	physics				LS2	physics
2011	2012	2013	2014	2015	2016	2017	2018	2019

- Civil engineering pre-study completed
- Civil engineering designed
- Civil engineering heavy workload done
- Building infrastructure & services ready



With this new building:

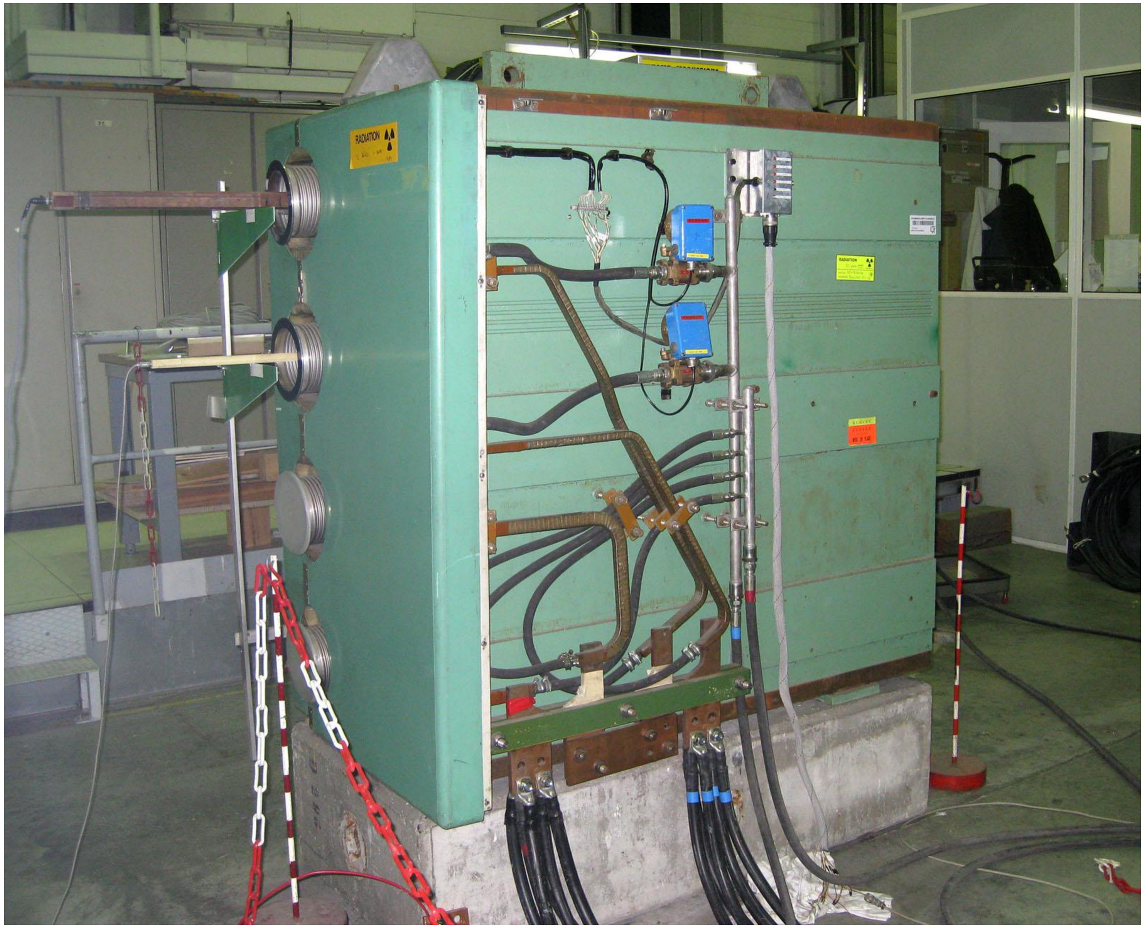
- We can install and commission during Booster operation.
- We have a backup power supply during the first years.
- Easy connection to existing cables and cooling services.



Magnets

- main dipoles can operate at 2 GeV with some modifications (cooling, retaining plates)
  - some concern about mechanical stress when pulsing at 2 GeV and 0.8 Hz

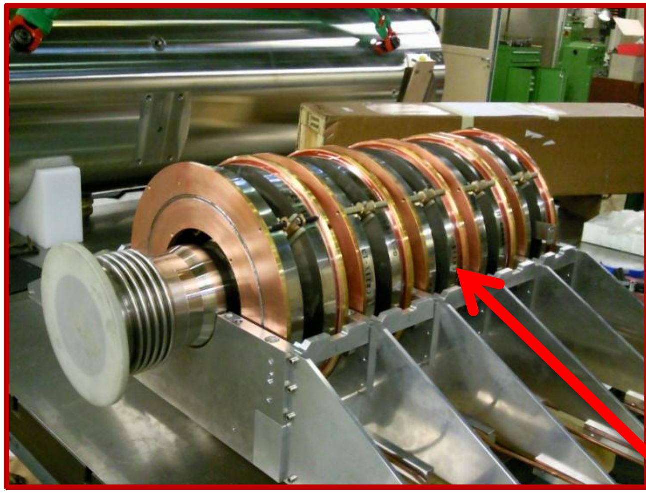
- number of other magnets to be changed



Booster main magnet undergoing tests for operation at 2 GeV

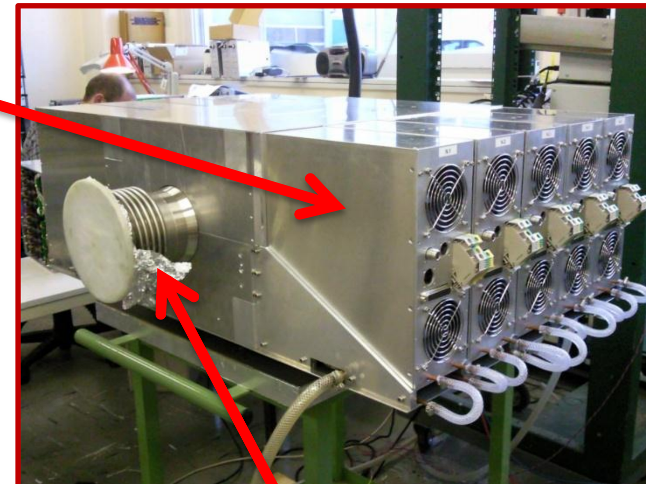
RF System

5-cells open cavity.

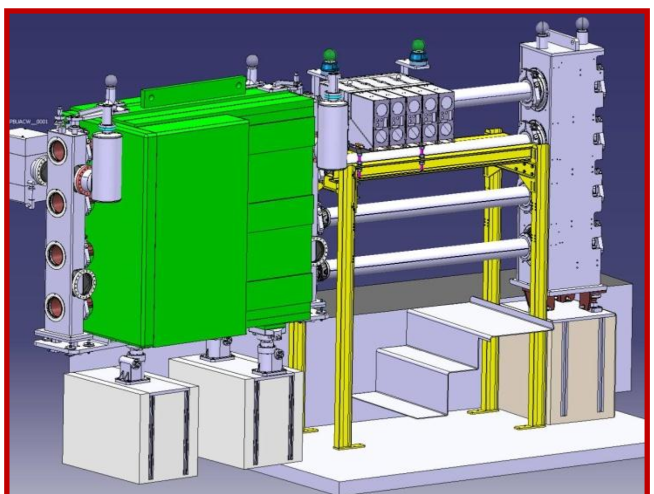


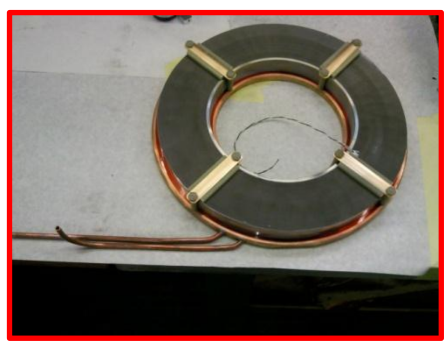
Solid-State amp.

Full assembly.



Installation layout in PSB 6L1.





Finemet® on a cooling ring.

Vacuum chamber.

M. Paoluzzi

Other Items

- **Cooling & Ventilation**
  - refurbishment of cooling station and some distribution piping
  - complete refurbishment of existing ventilation plant keeping the same functionalities

- **Electrical Systems**
  - re-design of the system has started

- **Beam Intercepting Devices**
  - new dump and beam stopper being designed
  - removal of the old and installation of the new dump being studied for LS1

- **Extraction & Transfer**
  - number of septa/kickers cannot operate at 2 GeV, notably extraction kickers (BE.KFA) and recombination septa (BT.SMV)

- **Other items:**
  - beam instrumentation, transport, controls, interlocks, design office, vacuum, etc. etc.

PSB Upgrade LIU Project

LIU-PSB WBS

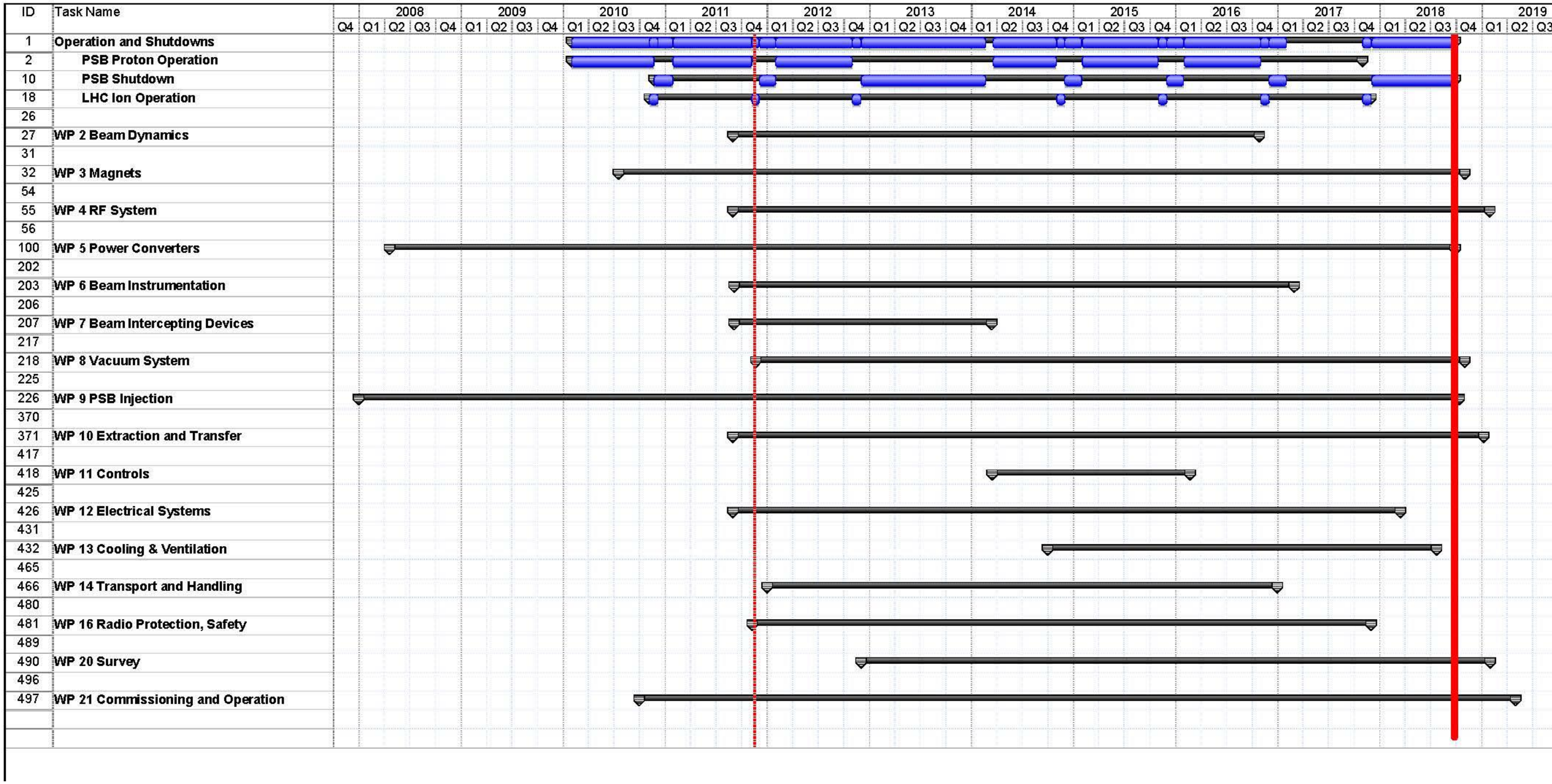
https://espace.cern.ch/liu-project/liu-psb/default.aspx

https://edms.cern.ch/document/1146814/12

Work-Package	Responsible	Unit
2.Beam Dynamics	C. Carli	BE/ABP
3.Magnets	D. Tommasini, A. Newborough	TE/MCS
4.RF Systems	A. Findlay, M. Paoluzzi, M.E. Angoletta, A. Blas, A. Butterworth	BE/RF
5.Power Converters	S. Pittet, D. Nisbet	TE/EPC
6.Instrumentation	J. Tan	BE/BI
7.Beam Intercepting Devices	O. Aberle, A. Massi	EN/STI
8.Vacuum System	J. Hansen	TE/VSC
9.L4-PSB Transfer and PSB Injection	W. Weterings, C. Carli	TE/ABT, BE/ABP
10.PSB Extraction and PSB-PS Transfer	J. Borburgh, W.Bartmann	TE/ABT
11.Controls	S. Jensen	BE/CO
12.Electrical Systems	D. Bozzini, S. Olek	EN/EL
13.Cooling and Ventilation	M. Nonis	EN/CV
14.Installation, Transport and Handling	I. Ruehl, C. Bertone	EN/HE
15.Civil Engineering	L.A. Lopez-Hernandez	GS/SE
16.Radiation Protection	J. Vollaire	DGS/RP
17.Interlock Systems	B. Puccio, P. Dahlen, B. Todd	TE/MPE
18.Alarms		--/---
19.Access Systems - Doors		--/---
20.Survey	T. Dobers	BE/ABP
21.Commissioning and Operation	B. Mikulec	BE/OP
22.Dismantling		--/---

PSB Upgrade
LIU Project

Time Lines



- Linac4 connection possible as from end 2015, constrained by LHC stops
- full upgrade including 2 GeV to be completed during LS2

BTY Line at 2 GeV

pre-study done by D. Voulot

can the BTY line handle the 2 GeV beams?

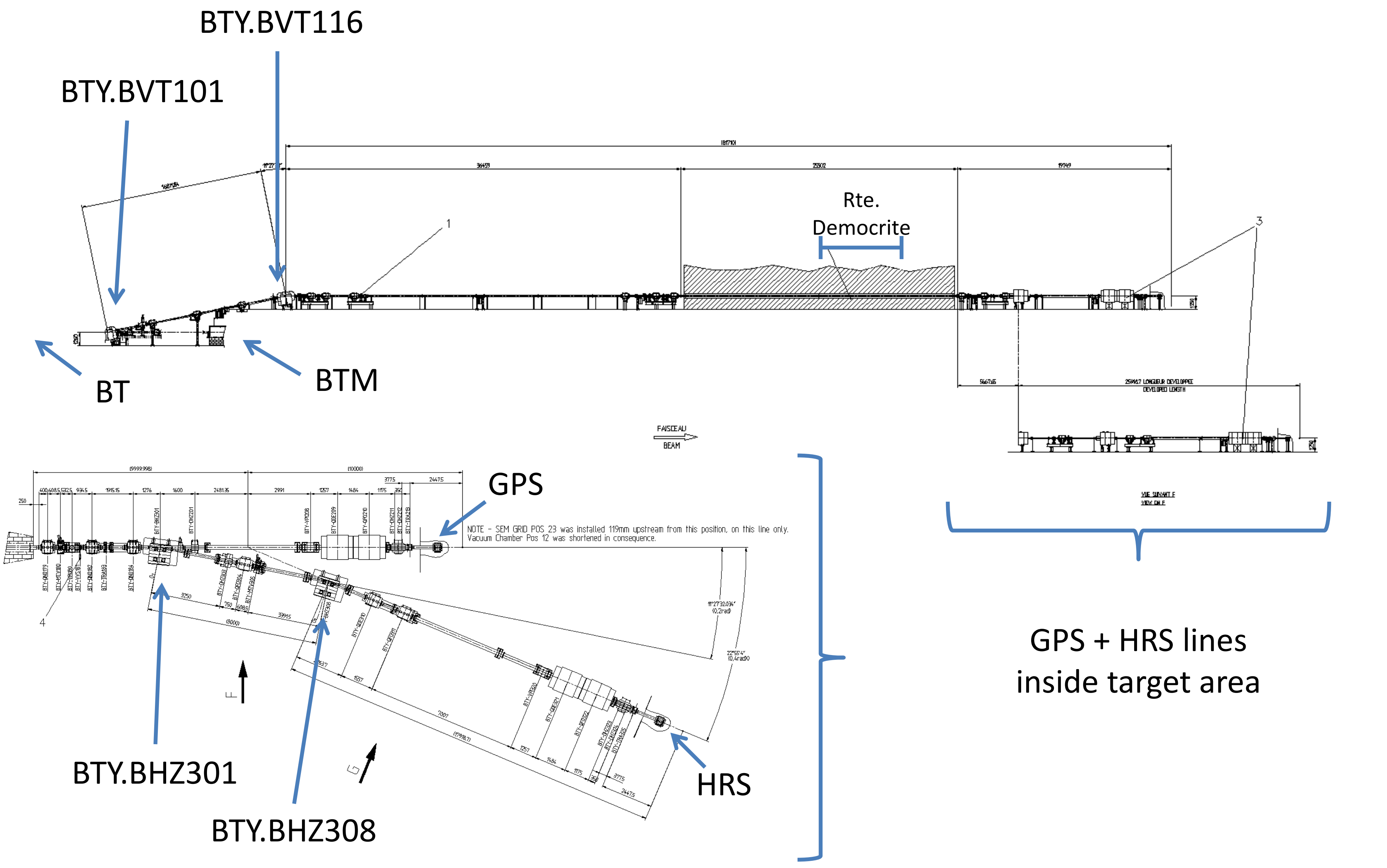
how many magnets/power supplies need to be replaced?

consequences for the shielding? beam intercepting devices?

assumptions:

- Consider BTY line only: BT, BTM are already covered by LIU
- Base settings:
  - NORM.GPS/NORM.HRS working sets
  - MAD files
- assume no change in optics
- **assume only 1.4 and 2 GeV available after the upgrade (PSB cannot provide both 1 and 2 GeV beams)**

BTY Line



D. Voulot

BTY Magnets

- quadrupoles
  - Q100 target focalization (4 units)
  - Q130 beam transport (15 units)
- dipoles
  - HB4 from former ISR transfer lines (4 units)
- correctors
  - type 1 H-V corrector magnets from PSB (14 units)
  - correctors have enough margin for 2 GeV

Quadrupoles

Quadrupole	type	Leq (m)	To GPS Carli 2003 k (m−2)	To GPS Carli 2003 1.4GeV I(A)	To GPS NORMGPS 1.4GeV I(A)	To GPS Calibration 2.0GeV I(A)	To HRS Carli 2003 k (m−2)	To HRS Carli 2003 1.4GeV I(A)	To HRS NORMHRS 1.4GeV I(A)	To HRS Calibration 2.0GeV I(A)	Magnet peak current I(A)	Power Converter specification U(V)	Power Converter specification I(A)
BTY.QDE104	Q130	0.56	-0.89	182.20	182.20	243.97	-0.89	182.20	182.20	243.97	220.0	60	220
BTY.QFO108	Q130	0.56	0.66	134.95	134.95	178.22	0.66	134.95	134.95	178.22	220.0	60	220
BTY.QDE113	Q130	0.56	-0.89	182.26	182.26	244.06	-0.89	182.26	182.26	244.06	220.0	60	220
BTY.QFO119	Q130	0.56	0.67	136.51	124.60	180.32	0.67	136.51	124.60	180.32	220.0	60	220
BTY.QDE120	Q130	0.56	-0.97	198.53	198.53	268.07	-0.97	198.53	198.53	268.07	220.0	60	220
BTY.QFO122	Q130	0.56	0.38	77.33	77.33	102.58	0.38	77.33	77.33	102.58	220.0	60	220
BTY.QFO148	Q130	0.56	0.23	47.31	47.31	63.49	0.23	47.31	47.31	63.49	220.0	60	220
BTY.QDE151	Q130	0.56	-0.56	113.90	113.90	150.26	-0.56	113.90	113.90	150.26	220.0	60	220
BTY.QFO153	Q130	0.56	0.38	77.06	77.06	102.23	0.38	77.06	77.06	102.23	220.0	60	220
BTY.QFO179	Q130	0.56	0.00	0.00	0.00	0.00	0.53	107.86	107.10	142.32	220.0	50	150
BTY.QDE182	Q130	0.56	-0.21	43.07	43.07	57.92	-0.81	164.67	164.62	218.97	220.0	60	220
BTY.QFO184	Q130	0.56	0.33	67.12	67.12	89.32	0.51	105.15	105.12	138.78	220.0	60	220
BTY.QDE209	Q100	1.15	-0.37	132.42	133.12	177.54					700.0	50	300
BTY.QFO210	Q100	1.15	0.40	140.07	140.81	187.99					700.0	90	350
BTY.QFO304	Q130	0.56					0.96	196.62	155.62	265.21	220.0	60	220
BTY.QDE310	Q130	0.56					-0.89	182.53	182.53	244.45	220.0	60	220
BTY.QFO311	Q130	0.56					0.75	153.53	152.53	203.49	220.0	60	220
BTY.QDE321	Q100	1.15					-0.53	186.10	186.11	248.97	700.0	50	300
BTY.QFO322	Q100	1.15					0.52	182.55	182.74	244.37	700.0	90	350

- some disagreement between calculated and actual settings (assume largest value)
- 5 quadrupoles exceed the limits (red), 3 within 10% of specifications (orange)
- new power supplies are required
- magnets can be upgraded → tests needed

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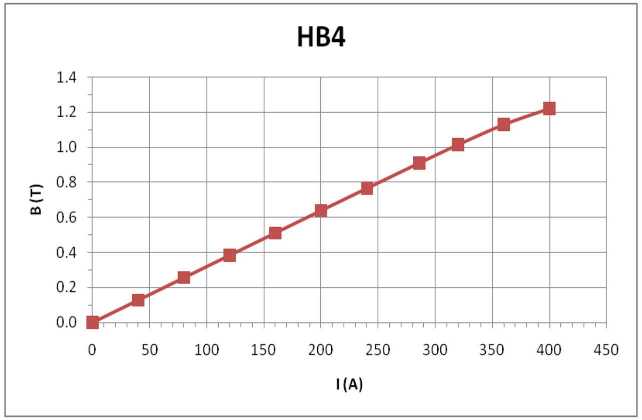
Dipoles

Dipole	type	To GPS		To HRS		Magnet peak current	Magnet peak field	Power Converter specification	
		NORMGPS 1.4GeV	Linear scaling 2.0GeV	NORMHRS 1.4GeV	Linear scaling 2.0GeV				
		I(A)	I(A)	I(A)	I(A)	I(A)	B(T)	U(V)	I(A)
BTY.BVT101	HB4	442.55	575.53	442.55	575.53	540.0	1.224	250.0	500.0
BTY.BVT116	HB4	447.00	581.32	447.00	581.32	540.0	1.224	70.0	500.0
BTY.BHZ301	HB4			449.52	584.59	540.0	1.224	250.0	500.0
BTY.BHZ308	HB4			453.00	589.12	540.0	1.224	70.0	500.0



- power converters cannot cope with the new currents → need to be replaced
- magnets can probably be upgraded to 600 A (increased water cooling) → need simulations and test
- calibration curve starts to show saturation above 350 A
- two dipoles need to become PPM (BVT101, BHZ301)
- special scheme used to go from zero to normal setting, cannot pulse quickly from normal setting to zero

D. Voulot

PPM Operation

- all quadrupoles operate in DC mode except BTY.QFO179, BTY.QDE182 and BTY.QFO184
- both magnets and power converters are designed for PPM operation
- PPM operation could help reduce water cooling needs by reducing the RMS currents
- test of power converters in PPM mode in December 2011 with 1 and 1.4 GeV settings
- OK for all units except:
  - 1 Q130: BTY.QDE120 (to be replaced anyway)
  - 2 Q100: BTY.QDE209 and BTY.QDE321
- need to test field stability with beam (planned for next start-up)

D. Voulot

BTY Magnet & Power Supply Summary

Logical Name	Model	Designation	Building	Vmax	Imax	magnet type	Limits		Setting 1 GeV		Setting 1.4 GeV		Setting 2 GeV		PPM at 1.4 GeV	2 GeV upgrade
							Imin	Imax	GPS	HRS	GPS	HRS	GPS	HRS		
BTY.BVT 101	B1/IEP-REC	IEP avec récupération 100kW	361	250	500	HB4			350.3		442.6		573.5			new 700A/±300V
BTY.BVT 116	A3/IP	InverPower 35kW	361	70	500	HB4			353.9		447.0		581.3			new 700A/±300V
BTY.BHZ 301	B1/IEP-REC	IEP avec récupération 100kW	197	250	500	HB4				355.9		449.5		584.6		new 700A/±300V
BTY.BHZ 308	A3/IP	InverPower 35kW	197	70	500	HB4				358.6		453.0		589.1		new 700A/±300V
BTY.QDE 104	MG-FWD	MG Free Wheel Diode [220A, 60V]	361	60	220	Q130	100	190	144.2		182.2		244.0		OK	reuse A3/IP
BTY.QFO 108	MG-FWD	MG Free Wheel Diode [220A, 60V]	361	60	220	Q130	50	140	106.8		135.0		178.2		OK	
BTY.QDE 113	MG-FWD	MG Free Wheel Diode [220A, 60V]	361	60	220	Q130	100	190	144.3		182.3		244.1		OK	reuse A3/IP
BTY.QFO 119	MG-FWD	MG Free Wheel Diode [220A, 60V]	197	60	220	Q130	50	150	98.6		124.6		180.3		OK	
BTY.QDE 120	MG-FWD	MG Free Wheel Diode [220A, 60V]	197	60	220	Q130	150	210	157.2		198.5		268.1		not OK	new A2/IP
BTY.QFO 122	MG-FWD	MG Free Wheel Diode [220A, 60V]	197	60	220	Q130	50	100	61.2		77.3		102.6		OK	
BTY.QFO 148	MG-FWD	MG Free Wheel Diode [220A, 60V]	197	60	220	Q130	30	60	37.5		47.3		63.5		OK	
BTY.QDE 151	MG-FWD	MG Free Wheel Diode [220A, 60V]	197	60	220	Q130	50	120	90.2		113.9		150.3		OK	
BTY.QFO 153	MG-FWD	MG Free Wheel Diode [220A, 60V]	197	60	220	Q130	50	100	61.0		77.1		102.2		OK	
BTY.QFO 179	S150A	S150A [±150A, ±50V]	197	50	150	Q130	0	150	0.0	84.8	0.0	107.1	0.0	142.3	OK	reuse MG-FWD
BTY.QDE 182	MG	MG [220A, ±60V]	197	60	220	Q130	30	120	34.1	130.3	43.1	164.6	57.9	219.0	OK	new A2/IP
BTY.QFO 184	MG-FWD	MG Free Wheel Diode [220A, 60V]	197	60	220	Q130	50	110	53.1	83.2	67.1	105.1	89.3	138.8	OK	
BTY.QFO 304	MG-FWD	MG Free Wheel Diode [220A, 60V]	197	60	220	Q130	100	200		123.2		155.6		265.2	OK	new A2/IP
BTY.QDE 310	MG	MG [220A, ±60V]	197	60	220	Q130	100	200		144.5		182.5		244.5	OK	new A2/IP
BTY.QFO 311	MG-FWD	MG Free Wheel Diode [220A, 60V]	197	60	220	Q130	100	200		120.8		152.5		203.5	OK	new A2/IP
BTY.QDE 209	A1/IP	InverPower 15kW	197	50	300	Q100	70	150	104.8		132.4		177.5		not OK	
BTY.QFO 210	A2/IP	InverPower 31.5kW	197	90	350	Q100	100	200	110.9		140.1		188.0		OK	
BTY.QDE 321	A1/IP	InverPower 15kW	197	50	300	Q100	100	200		147.3		186.1		249.0	not OK	
BTY.QFO 322	A2/IP	InverPower 31.5kW	197	90	350	Q100	120	220		144.7		182.7		244.4	OK	

Courtesy S. Pittet

- need nine new power supplies and reassign three
- keep Q100 BTY.QDE209 and BTY.QDE321 in DC
- operate all other quadrupoles in PPM between 2 GeV and lowest possible value → need to adjust the limits
- same mode of operation for the two switching dipoles (3-way PPM, cannot switch down in consecutive pulses) → need test

Power Supply Summary and Cost Estimate

Logical Name	Setting 2 Gev [A]	Setting 2 Gev +10% [A]	Upgrade cost @2GeV [kCHF]	
BTY.BHZ 301	585	644	500	new 700A/±300V
BTY.BHZ 308	590	649	500	new 700A/±300V
BTY.BVT 101	576	634	500	new 700A/±300V
BTY.BVT 116	582	640	500	new 700A/±300V
BTY.QDE 104	244	268	0	reuse A3/IP
BTY.QDE 113	244	268	0	reuse A3/IP
BTY.QDE 120	268	295	160	new A2/IP
BTY.QDE 182	219	241	160	new A2/IP
BTY.QDE 310	245	270	160	new A2/IP
BTY.QFO 179	142	156	0	reuse MG-FWD
BTY.QFO 304	265	292	160	new A2/IP
BTY.QFO 311	204	224	160	new A2/IP
			2800	

Courtesy S. Pittet

- total cost for power supplies ~2.8 MCHF
- largest cost item are dipole supplies (need high power for switching)
- the cabling for the four dipoles needs to be replaced ~37 kCHF
- assume all magnets can be kept

RP and Shielding

- radiation will scale with power (no significant change in cross sections between 1.4 and 2 GeV)
- BTY shielding design was very conservative (AH Sullivan 1993)

  assuming that: ‘1% of the maximum beam, or 0.2% per meter of beam path, could be lost anywhere continuously along the beam line’

  ‘maximum losses for which hand-on maintenance of the accelerator component would be possible due to the high residual dose rate (several mSv/h near the beam line)’
- in reality losses and residual dose rates are many orders of magnitude lower (several uSv/h)
- shielding is not expected to be an issue even for a four fold increase of the beam power (2.8 →10 kW)
- need more detailed analysis plus RP survey after power upgrade

Beam Intercepting Devices

main concern: beam stopper

- not water cooled
- designed for lower beam power
- replacement of all beam stoppers foreseen as part of the PS complex consolidation

other beam intercepting devices: SEM-grids, MTVs

- standard diagnostics used elsewhere in the PS complex
- should stand the power increase

D. Voulot

LIU-PSB Summary

- initial Task Force has turned into an approved project within LIU
- TDR to be written
- ongoing MD activity during the next years
- some work during coming winter stops (removal ion distributor, Finemet test installation, …)
- some work to be done during LS1: change of the Booster dump, renovation of handling equipment, cables?, …)
- most work in LS2 (complete hardware upgrade); if Linac4 connection could be advanced, this would reduce the stress on the intervening groups and on the recommissioning, and is therefore the preferred scenario
- if Linac4 and the 2 GeV upgrade will coincide in LS2, we will have a lot to do

BTY@2GeV Summary

- upgrade to 2 GeV feasible at a total cost of about 2.8 MCHF
- assume all magnets can be upgraded
  →need extra cooling
  →need simulations and tests
- PPM operation would help saving power and cooling needs
  →initial test in December, test with beam next spring
- at first glance little concern with shielding and beam intercepting devices (need more detailed analysis)
- have not assessed targets and target area, only BTY line!
- see https://edms.cern.ch/document/1178703/1.0

- **not part of LIU!** / would need its own little project & funding

The 2 GeV Booster for the beams to the PS is approved and will come by LS2. If ISOLDE wants to take advantage of the increased energy, clear interest must be stated and things need to be brought on their way rather soon.